The WELDING JOURNAL

FEBRUARY 1953

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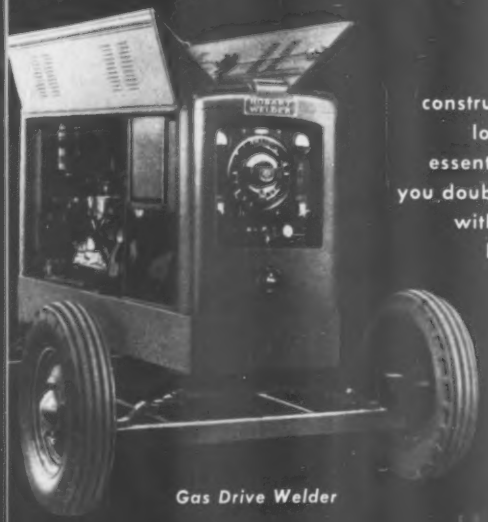

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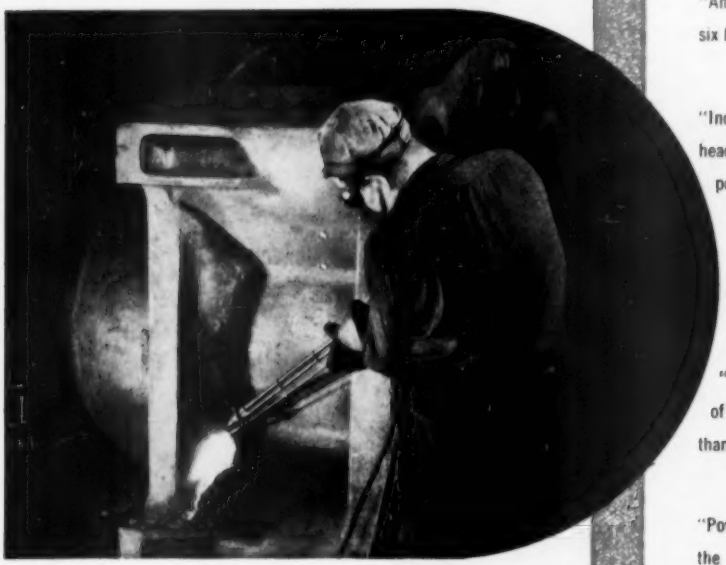

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The WELDING JOURNAL

volume 32 February 1953 number 2

Shielding Arc-Welding Processes for Jet-Engine Components

An analysis of when and how to use each of the inert-gas-shielded arc processes and submerged arc in the fabrication of jet engine components

by K. H. Koopman

INTRODUCTION

WELDING processes of all types offer many opportunities for reducing costs and labor in jet-engine fabrication by allowing use of smaller and simpler subassemblies which are then welded together. Large expensive forgings or plate sections requiring considerable machining can be eliminated in many cases. This paper attempts to show when inert-gas-shielded tungsten arc, inert-gas-shielded metal arc and submerged arc welding can logically be used for welding various jet-engine components. Four main subjects are discussed: Welding processes, advantages, apparatus and typical applications.

FACTORS AFFECTING SELECTION OF WELDING PROCESSES

The functional design of jet-engine parts is tied in closely with material properties at high temperatures. Materials selected for the parts have a bearing on welding problems. Design engineers should and do consider material selections carefully, since some high-temperature alloys have more desirable weldability characteristics along with equivalent physical and mechanical properties. Production supervisors are expected to overcome processing problems by devising new or modified fabrication techniques. Figure 1 shows that jet engines are made of complex shapes of thin metal which can be fabricated best or only by welding. This is in contrast to reciprocating engines where practically all parts are machined, forged or cast, and very little welding is used.

Before describing details of the various welding processes that are being used, the following factors are listed with a recommendation that they be considered first before starting production welding of high-temperature alloys, regardless of the alloy being welded, the filler rod used or the welding process selected:

1. Welds in high-temperature alloys should be evaluated on the basis of properties shown by high-temperature test results, not room-temperature test results.

Fig. 1 Thin metal parts are used in jet engines

K. H. Koopman is Development Engineer with the Linde Air Products Co., Newark, N. J.

Presented before the Thirty-Third National Fall Meeting, AWS, Philadelphia, Pa., week of Oct. 20, 1952. Closing date for discussion Apr. 15, 1953.

2. Weld, not base metal, physical properties should be used to evaluate weld properties.

3. Five percent elongation at operating temperature is sufficient ductility to relieve high nonuniform stresses, by allowing localized plastic deformation.

4. The silicon content in cast alloys should be kept on the low side of specifications to reduce hot-cracking tendencies.

5. The correct balance of minor alloying additions should be and is being investigated to improve the weldability of many alloys.

6. The weldability of some of the "superalloys" appears to be very poor during preliminary test work. Most process difficulties can be overcome by careful examination of the welding techniques employed. For example, the weldability of a given alloy will vary somewhat for the different welding processes. Do not be alarmed if an alloy can be welded easily with one process but not with another at first try.

7. As the scarcity of rarer alloy elements forces the use of lower strength alloys, better designs will have to be and are being resorted to, such as:

(*a*) Placing welds at or near neutral axes.
(*b*) Air cooling of hot parts
(*c*) Using more weld combinations of dissimilar alloys; using the expensive and scarce alloys only in those areas where absolutely needed.
(*d*) Using fusion butt welds in place of resistance lap welds.

All three of the welding processes discussed in this paper supplement each other, but each one has definite advantages for a given thickness and metal. Each process is described and discussed below.

HELIARC* WELDING—INERT-GAS-SHIELDED TUNGSTEN-ARC

Heliarc welding is an arc welding process employing an inert-shielding gas—usually argon—which envelops and protects the virtually nonconsumed tungsten electrode, the arc, and the weld puddle from the atmosphere. Welds made with this process are flat, smooth and clean because no flux is used. This results in reduced finishing costs.

Jet engines have a high ratio of horsepower per pound of weight compared to reciprocating engines, and designers strive constantly to increase that ratio. One of the immediate advantages of inert-gas tungsten-arc welded butt joints is weight saving. Factors favoring butt joints are shown in Fig. 2 and should be considered whenever the opportunity arises to recommend joint preparations.

Another advantage of inert arc welding is that apparatus investment and maintenance costs are relatively low. It also offers the outstanding advantages of greater adaptability to a wide range of metal thicknesses and types, as well as the valuable feature of greater portability. Availability of sufficient welding power supply is another factor that offers fewer problems in the application of tungsten-arc welding. All of these points become more important as the size of the welding shop decreases, and probably are most important of all to the small subcontractor who must purchase most of the equipment he needs before production can be started. He can get into business rapidly.

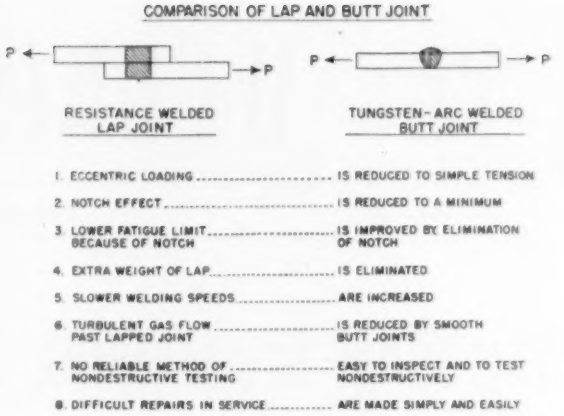
COMPARISON OF LAP AND BUTT JOINT
P
P
P
P
RESISTANCE WELDED LAP JOINT
TUNGSTEN-ARC WELDED BUTT JOINT
1. ECCENTRIC LOADING
IS REDUCED TO SIMPLE TENSION
2. NOTCH EFFECT
IS REDUCED TO A MINIMUM
3. LOWER FATIGUE LIMIT BECAUSE OF NOTCH
IS IMPROVED BY ELIMINATION OF NOTCH
4. EXTRA WEIGHT OF LAP
IS ELIMINATED
5. SLOWER WELDING SPEEDS
ARE INCREASED
6. TURBULENT GAS FLOW PAST LAPPED JOINT
IS REDUCED BY SMOOTH BUTT JOINTS
7. NO RELIABLE METHOD OF NONDESTRUCTIVE TESTING
EASY TO INSPECT AND TO TEST NONDESTRUCTIVELY
8. DIFFICULT REPAIRS IN SERVICE
ARE MADE SIMPLY AND EASILY

Fig. 2 Butt joints in jet engine parts increase the ratio of hp/lb of weight which is an important consideration. Other advantages of butt joints over lap joints are also listed

A sufficient variety of part shapes and contours occurs in jet-engine components so as to utilize all types of tungsten-arc welding apparatus. Manual, mechanized and semiautomatic inert-arc welding apparatus are all available. The choice depends upon the application. Practically all the metals used in jet engines can be inert arc welded. An impression of the wide use of this process can be gained by examining the typical jet-engine welding applications listed in Table 1. Most of these utilize Heliarc welding.

Listed below, as a summary, are the principal factors that should be considered in order to make the best use of inert arc welding for each application. It is believed that this list will also help the welding supervisor and his operators solve process troubles on many welding applications.

1. Joint design, preparation and alignment should be good. Mechanical wire brushing or buffing improves the quality of welds made in many metals.

2. Weld backing. Metal such as copper, steel or stainless steel; gas such as argon, helium, nitrogen or burning hydrogen; or flux, depending upon metal and type of joint being welded.

3. Welding speed. The correct speed range reduces weld hot-cracking and undercutting along the joint edges.

4. Welding current range.

5. Type of welding current. DCSP reduces hot-cracking because the narrow weld results in lower contraction stresses and also faster cooling through the hot-short temperature range.

* The term "Heliarc" is a registered trade mark of Union Carbide and Carbon Corp.

EDITORIAL NOTE: In order to avoid continued use of this trade name "inert arc" is used interchangeably with this term.

Table 1—Typical Jet Engine Fusion Welding Applications

Name of component	*Joint type*	*Metal, thickness, in.*	*Alloys used*	*Methods of welding*
Air compressor Stator casings	Girth butt	0.075 to thicker flanges	Low-alloy steels and Type 410SS	Mechanized inert arc and Unionmelt (sigma should be tried on some alloys)
Compressor blades	Edge and lap fillet	0.050–0.075	Type 410SS	Manual inert arc
Air diffuser assembly	Edge and lap fillet	0.062–0.093	Type 410SS	Manual inert arc
Combustion chamber and liners	Longitudinal and girth butt	0.031–0.050	Groups I and II alloys	Mechanized inert arc (semi-automatic should be tried also)
Combustion chamber attachments	Lap and fillet	0.031–0.050	Groups I and II alloys	Manual inert arc
Transition ducts	Spot and butt	0.031–0.050	Groups I and II alloys	Mechanized and manual inert arc
Nozzle diaphragm assembly	Butt and lap	0.050	Groups I and II alloys	Inert arc manual and semiautomatic
Nozzle cones	Butt	0.050–0.125	Group II alloys	Mechanized sigma
Turbine casings	Butt	0.093–0.125	Aluminum clad steel and Group I alloys	Mechanized inert arc (sigma and submerged arc being tried)
Aft frames	Girth lap, fillet and corner welds	1/16, 1/8, 3/16, 1/2	Group I alloys	Inert arc manual and semi-automatic, mechanized sigma and submerged arc
Turbine wheels	Butt	0.5–2.0	Low-alloy steel Groups I, II and III alloys	Mechanized sigma and submerged arc
Outer and inner exhaust cones	Longitudinal and girth butt	0.050 and 0.063 to itself and to thicker flanges	Groups I and II alloys	Mechanized inert arc
Afterburner casings and exhaust cones	Longitudinal butt	0.050–0.063	Groups I and II alloys	Mechanized inert arc
Afterburner attachments and auxiliary parts	Butt, fillets and lap	0.050–0.090	Groups I and II alloys	Manual inert arc
Many experimental parts	Butt, fillets and lap	0.050–1.00	Titanium and its alloys	Manual and mechanized inert arc

6. Correct arc length. Use the shortest arc possible so as to produce a narrow weld to reduce hot-cracking. About 0.040 to 0.060 in. is normally used.

7. Correct tungsten electrode diameter. Use the smallest electrode that will carry the required current. This will give a narrow weld and so reduce hot-cracking.

8. Adequate gas shielding. Use the lowest flow that will still give a clean sound weld.

9. Welding rod composition. It may have to differ from the base metal composition to reduce weld hot-cracking.

10. Vertical and lateral location of rod feed in machine welding. Correct location governs weld flatness.

11. Correct welding technique and sequence in manual welding. Special procedures may be required to reduce hot-cracking or distortion.

12. Base metal composition and its weldability. Some metals have a greater tendency toward distortion, hot-cracking, porosity or oxidation than others.

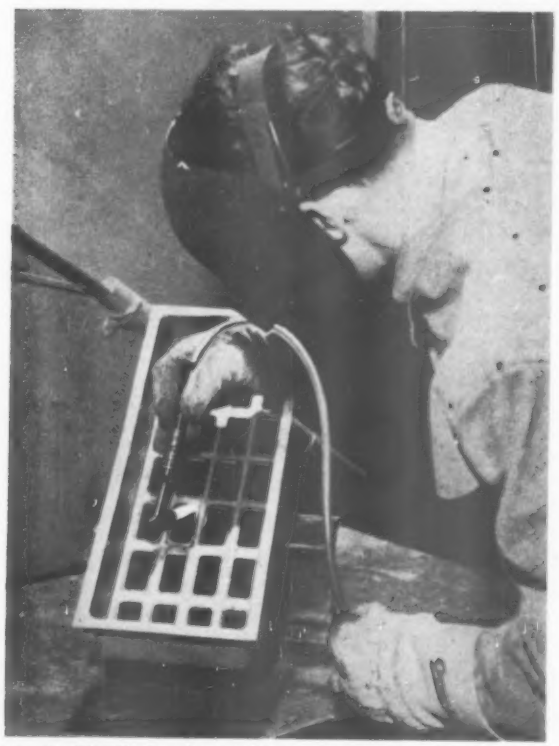

Fig. 3 The lightweight HW-9 torch will handle thin-gage materials up to about 16 gage

HELIARC WELDING APPARATUS

Many welds in jet-engine parts are so short, are in such confined spaces, or are so sharply curved that manual welding is the most logical choice. The HW-9 Heliarc torch, weighing only 3 oz, was designed primarily for such jobs. This torch is shown in Fig. 3. With a 75-amp capacity, the HW-9 torch will handle thin-gage materials up to about 16 gage. It is small enough to reach inside the more complicated weldments where there is little room for manipulation, and is useful for repairs of engine parts, after the engines have been in service for some time and must be overhauled. Manual welding torches with higher capacity ratings probably are preferred to the HW-9 in cases where constant use under severe shop service is necessary. A higher

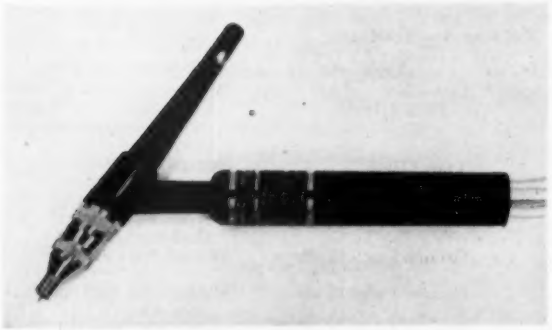

Fig. 4 The 300-amp, HW-10 can be used for thin metals or multipass welding of heavier materials

capacity, 300-amp torch, illustrated in Fig. 4, can be used for single-pass welding of the thinnest metal or for multipass welding of the thickest metal. Figures 6, 8 and 9 show some typical Inconel, stainless steel and carbon steel components welded with these manual torches.

WELDING RECOVERY UNITS

Components used in a power recovery unit are shown in Fig. 5. Three parts which are to be welded are shown along with various stages of the weldment. Three of these smaller assemblies are welded together as shown in Fig. 6. All of the butt welds in this heavy Inconel are made manually, and are backed with argon. Welds are straight butt with 100% penetration. Finishing operations consist of light grinding only on points of fit-up.

After the subassemblies are prepared they are welded to a cast stainless steel mounting ring, Fig. 7. Here the operator is getting ready to make the final weld.

OTHER TYPICAL WELDMENTS

Other typical weldments produced by inert arc welding are shown in Fig. 8. *A* is a mild steel bracket, for an unspecified use in a jet plane. A critical part, the bracket is X-rayed and magnafluxed. *B* is a mild steel junction box for a jet. The box is stamped out and formed, and then welded at four corners with an inert arc torch. A quick, light grinding is all that is needed

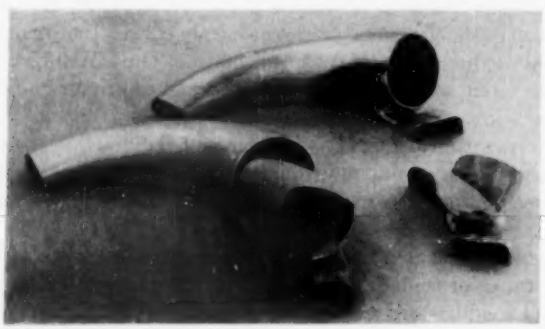

Fig. 5 Different stages of a welded subassembly used in a power recovery unit

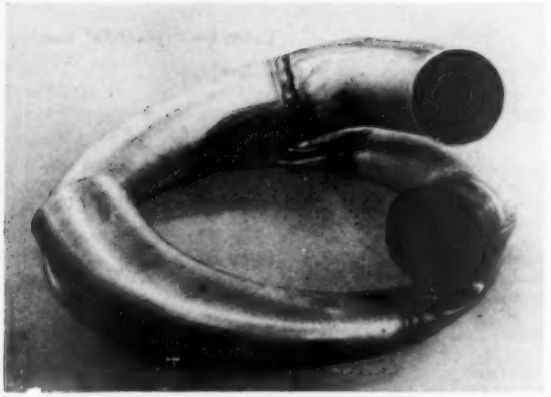

Fig. 6 Three subassemblies welded together before being welded to a mounting rig

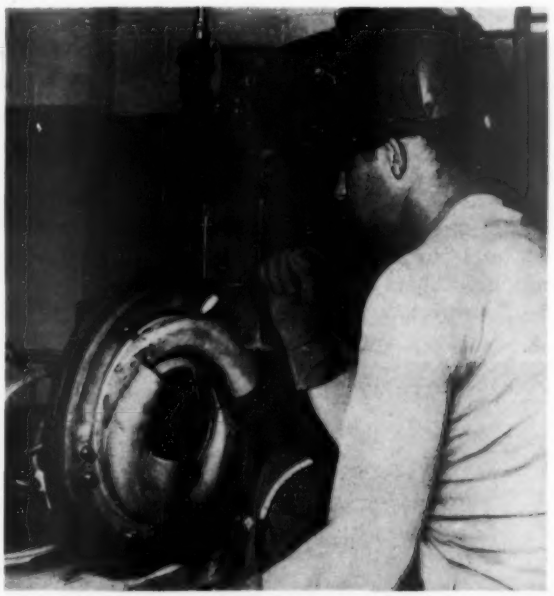

Fig. 7 Here an operator gets ready to make the final weld

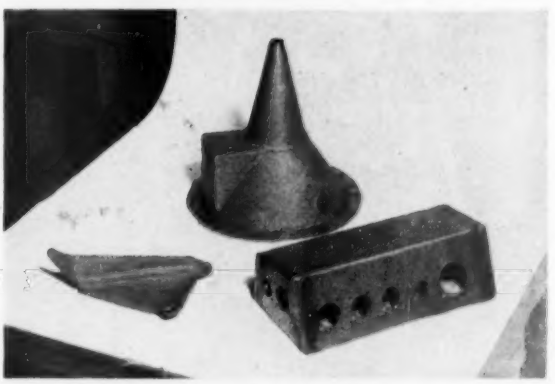

Fig. 8 Typical parts used in jet engines and produced by Heliarc welding

Fig. 9 No finishing is done on these high-temperature jet engine parts produced by inert arc welding

to finish this part. About 40 in. of inert arc welding is done on *C*, a turbine scavenger oil pump support. Material is Type 321 stainless steel, 0.050 in. thick, welded to a cast stainless ring.

Figure 9 shows several Heliarc welded high-temperature jet-engine parts made from stainless steel and Inconel X. No grinding is done on the welds. A closeup of a weld is shown in Fig. 10. This part is a combustion chamber housing. After welding, the joint is lightly wire brushed, and then inspected. Note the inspector's "OK" stamped along the weld.

Fig. 10 Close-up of an inert arc weld. Note inspector's "OK" stamps

In Fig. 11, a fillet weld is being made in heavy-walled stainless tubing, Type 347. This part is used in fuel ring fittings. An HW-9 torch is used with current about 30 amp.

Fig. 11 An HW-9 torch is used to make a fillet weld in stainless steel tubing

MECHANIZED WELDING

One of the chief factors tending to discourage manual welding is the degree of operator skill required. It has been believed, with some justification, that most reliable results are obtained when the "human element" is reduced as much as possible. Mechanization has proved practical to the greatest extent in high production industries, such as the manufacture of automobiles. Many of the jet-engine subcontractors are automobile manufacturers, and therefore are reluctant to use manual methods to any extent.

Exhaust cones, afterburners, turbine cases and other shrouding sections offer a number of possibilities for mechanized longitudinal and circumferential butt welding. Most of these welded joints require auxiliary filler rod addition. Inert-arc machine welding can be done with or without arc voltage control, depending upon the weld joint design. Some automatic inert arc equipment for machine welding with arc voltage control is shown in Figs. 12 and 13.

Machine welds in material over 18 gage in thickness are usually made with filler metal, although rod addition is sometimes used on metal as thin as 0.035 in. The rate of rod feed depends upon the amount of weld reinforcement desired. Highly accurate rod feed mechanisms are available which have an electronic speed control for maintaining a uniform rod feed rate.

Experience gained from practical applications indicates that mechanized tungsten-arc welding with auxiliary rod feed requires careful attention to all welding conditions and principal welding factors listed previously in this paper. Welding conditions must be maintained precisely to obtain consistently uniform re-

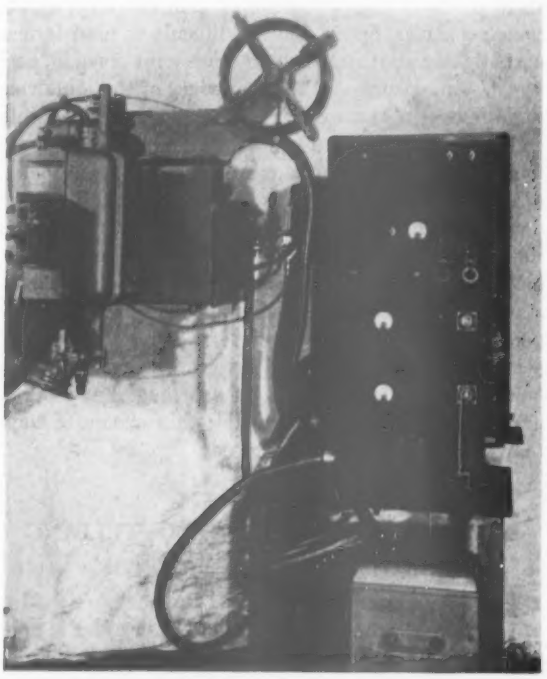

Fig. 12 Automatic Heliarc welding equipment for machine welding

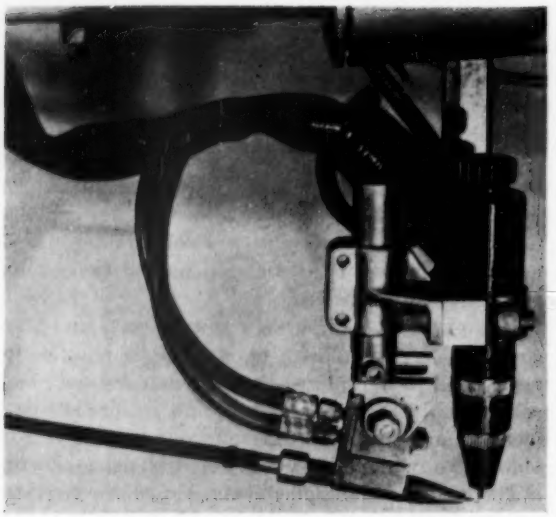

Fig. 13 Close-up of the Heliarc HW-13 machine torch and rod feed unit

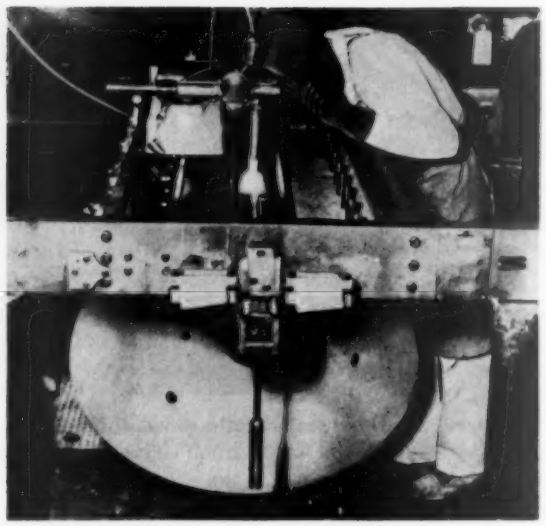

Fig. 14 An inert-arc machine-welding setup helps fabricate strong exhaust cones

sults in penetration and in coalescence of abutted sheet edges. Satisfactory results have been produced only in those cases where more than the usual amount of effort has been expended. Mechanized welding applications are increasing, and the fabrication of large numbers of jet-engine components will hasten "push-button" welding.

Another problem in mechanized welding is the control of initial joint gap settings, assuming that the fixture holds the parts firmly after pressure is applied. This point refers specifically to the dimensional tolerances of parts prior to welding. For example, experience has shown that it is very difficult to hold formed parts tightly abutting or to an exact joint opening, such as a $^1/_{32}$-in. spacing. Trimmed edges of the joint vary sometimes so that the edges are touching at some points, and separated by $^1/_{32}$ to $^1/_{16}$ in. at other points along the joint. Penetration and reinforcement are affected directly and adversely by these conditions. It is mandatory to prepare joint edges straight and to hold gap spacing closely to get consistently good results with mechanized welding. Most fabricators fail to understand the complexities of jigging until they have expended considerable time and effort trying to weld parts using ordinary practices. Precise settings must be held. Even minor variations are magnified a great deal when mechanically welding thin sheets of high-temperature metals at high speeds.

SUMMARY OF MECHANIZED WELDING ADVANTAGES

The advantages of mechanized tungsten-arc welding can be summarized as follows: (1) Lower order of operator skill is required. (2) Increased production is possible. (3) Welding costs are reduced. (4) More uniform weld quality is obtained.

TYPICAL APPLICATIONS

Longitudinal seams for large engine exhaust cones are welded at 16 ipm in the mechanized inert-arc welding setup shown in Fig. 14. Little finishing is required on the strong even welds. Exhaust cones are simply clamped in the machine, while the required butt weld is made.

Figure 15 shows another mechanized inert-arc welding setup. Here, tail cones are joined. Originally, they were made with another welding process which required more setup time and use of more tools. With inert arc welding, the cones are simply clamped in the fixture, and the Heliarc machine runs over the seam to make a clean, sound butt weld.

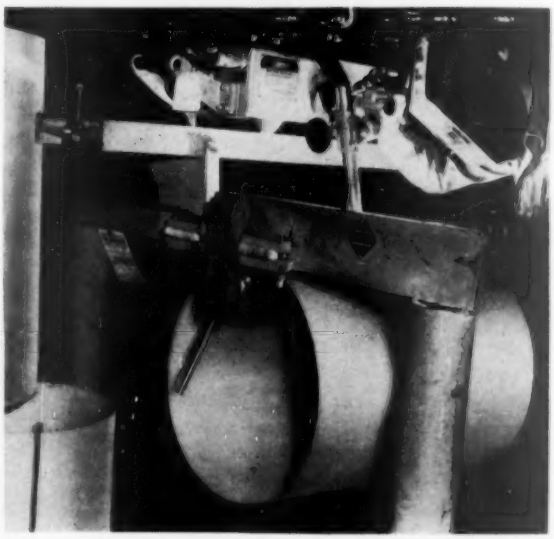

Fig. 15 Here, tail cones are joined

SEMIAUTOMATIC WELDING

A joint that changes contour in more than one plane generally will prohibit the use of fully mechanized welding, whereas manual welding speeds may not be high enough to satisfy high production demands. Semiautomatic welding with the HWM-1 outfit was developed to bridge the gap between manual and mechanized welding. It is useful for straight-line or circumferential butt seams in material up to about $^{3}/_{32}$ in. thick where full penetration is desired in a single pass. It is used on lap joints also. Since single-pass penetration is more difficult to obtain on thicker materials, sigma or submerged arc welding would be a better choice on thickness of about $^{3}/_{32}$ in. and greater because these processes will give good penetration at higher welding speeds.

DESCRIPTION OF APPARATUS

Semiautomatic welding utilizes filler rod drawn from a reel by powered drive rolls, and fed into a tungsten-arc weld puddle through a flexible cable and nozzle attached to a modified manual welding torch. The rod issuing from the nozzle, at a constant but adjustable feed rate, is pressed against the joint to be welded. The pressure required is not great, but there must be enough to prevent rod slippage. The rod issuing from the nozzle therefore becomes the "propelling" means for the torch; and it is melted under the arc to join adjacent base metal edges at the rate of approximately 1 in. of weld per inch of rod. Welding speed therefore is about the same as the preset rod feed rate. The Heliarc HWM-1 Semiautomatic Welder is shown in operation in Fig. 16.

Fig. 16 The Heliarc semiautomatic welder will easily follow joints with changing contour

WELDING FIXTURES

The lack of adequate jigging has been one of the principal deterrents to successful mechanized welding. Insufficient hold-down pressure allows sheets to "crawl" which results in varying joint gap spacing between the start and finish ends of the weld. Penetration and weld bead contour are affected by the changes in joint opening, creating problems of strength variation and excessive finishing required to remove reinforcement. Hold-down pressures as high as 400 to 500 lb per linear inch are required to prevent sheet movement. Although greater fixture expense is necessary to produce these high clamping pressures, fixture makers are beginning to realize this condition and are now supplying well-designed fixtures.

The weld backup bar is another important item in the fixture because it governs heat distribution in the joint by appropriate chilling effects. Copper backup bars with relief grooves are recommended for welding many of the high-temperature alloys. Copper offers good control of chilling effect because of its high heat conductivity and because it will not fuse to the bottom of the weld bead. Relief grooves provide the most reliable method of controlling heat distribution uniformly, at the same time allowing good weld penetration without drop-through.

Gas backing and flux backing are also useful. Argon, helium, nitrogen or burning hydrogen are used, depending upon the metal and weld joint design. If a flux backing is used, it should be low in boron compounds to prevent formation of flux-metal eutectics having low ductility and melting point.

SIGMA WELDING

The sigma (*shielded-inert-gas metal-arc*) process uses a consumable electrode as contrasted to the virtually nonconsumable tungsten electrode of the inert-gas-shielded tungsten-arc or Heliarc process. Either hand or fully automatic equipment is available, as illustrated in Figs. 17 and 18.

SCOPE OF USE

Sigma welding has a substantially higher rate of heat input and therefore is most useful for butt welding of material about $^{2}/_{32}$ in. or thicker and fillet welding of $^{1}/_{16}$ in. and thicker.

Although material as thin as 0.025 in. has been machine-welded at high speed, the weld reinforcement is too

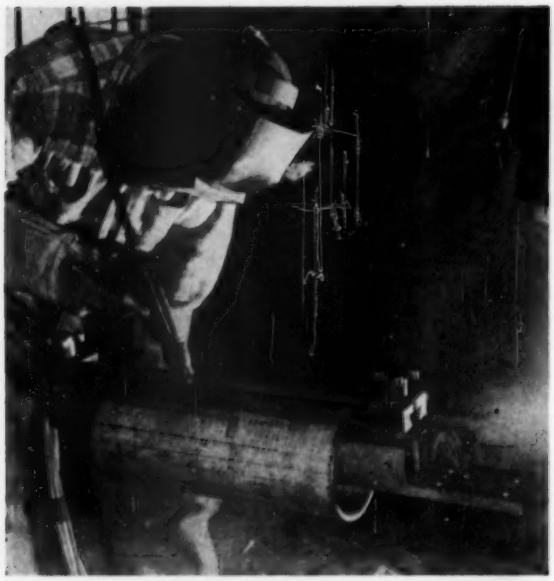

Fig. 17 A sigma hand welding torch is easy to handle

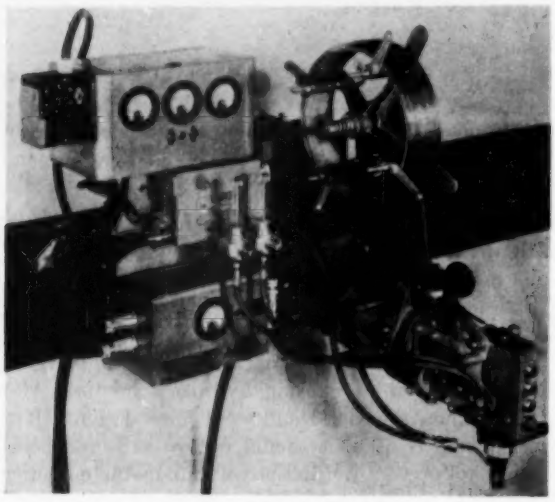

Fig. 18 A fully automatic sigma welding machine

great on butt-welded material less than $^3/_{32}$ in. thick for most applications. However, for fillet welding, the process is useful for machine welding of material down to 16 gage. Manual welding is applicable to fillet and lap joints of $^3/_{32}$ in. and over, and butt welds of $^1/_8$ in. and thicker.

The best possibilities for sigma welding appear on the functional parts of jet engines, as opposed to the "skin" or shrouding parts. Experiments are being conducted on turbine wheels, for example, where reasonably thick sections might be welded better with the sigma process. This particular application has not been reduced to practice in production, but work is continuing. Another use for sigma machine welding is in the fabrication of nozzle vanes, which are formed by folding 0.050-in. thick Stellite No. 25 sheet stock and welding

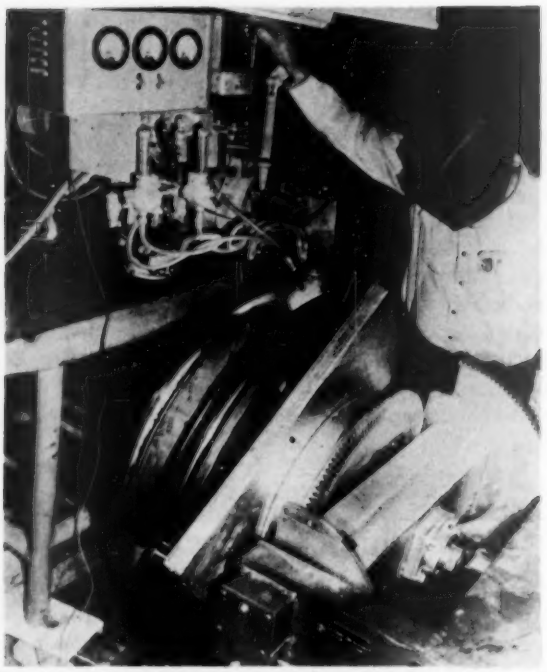

Fig. 19 A large stainless steel jet engine component is welded with a sigma welding machine

the two edges to $^1/_8$ in. thick Stellite No. 25 blade extensions.

An investigation is now under way to develop conditions for both sigma and submerged arc welding of turbine wheels joining 2-in. thick SAE 4340 steel hubs to Timken 16-25-6 rims It appears that both processes will be successful in producing crack-free welds when using Type 312 rod provided dilution with the austenitic 16-25-6 alloy is held low enough to retain about 5% ferrite in the austenitic weld metal. The process selected will be the one that gives acceptable weld quality at the lowest cost. A typical sigma application is shown in Fig. 19 and others are listed in Table 1, together with some Heliarc and Unionmelt applications.

WELDING FACTORS

To help make the best use of this welding process for each application, the best possible welding conditions should be established. To accomplish this, the same principal factors should be considered as in the case of tungsten arc welding except that a consumable electrode rather than a tungsten electrode, and DCRP welding current are normally used. An additional factor of inclination of work is important. Welding uphill increases penetration, whereas welding downhill gives a wider, flatter weld bead and permits faster welding on thin material.

SUBMERGED ARC OR UNIONMELT* WELDING

Another fusion welding process that is being used for

* The term "Unionmelt" is a registered trade-mark of Union Carbide and Carbon Corp.

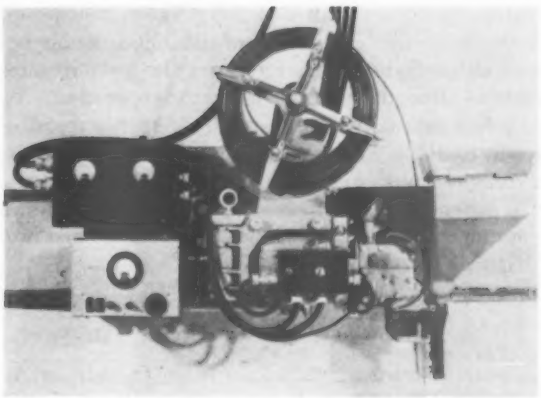

Fig. 20 A typical Unionmelt welding machine, Type UE-48

fabricating jet-engine components about 14 gage and thicker is submerged arc or Unionmelt welding. A typical Unionmelt welding machine, the UE-48 model, is shown in Fig. 20. This process is lower in cost than sigma welding for machine-welding applications, because the Unionmelt composition used to cover and protect the weld is less costly than the inert gas used in sigma welding. Larger diameter and lower cost rod is also used for submerged arc welding. In general, submerged-arc welding speeds are substantially higher than those possible with other fusion welding processes. Although alloy losses during weld metal transfer are somewhat greater in Unionmelt welding as compared to Heliarc or sigma welding, effective control of weld metal composition is obtained through the choice of granular Unionmelt material and welding rod alloy content. These will produce desirable metal-flux reactions during welding.

Because of low welding cost, high welding speed and easy production of desirable weld metal properties, mild steel and low-alloy steel jet-engine components, such as air-compressor stator cases, should be welded with the submerged-arc process. As an example, some 14-gage NAX low-alloy steel compressor cases are being submerged arc butt welded at 100 ipm. Severe undercutting along each side of the weld would have occurred at speeds far less than this with any other fusion welding process. Welding costs would also be far higher with other processes. In addition, the submerged-arc welding process provides a high degree of operator comfort, because the arc is submerged. Very little arc flash, heat radiation or fuming occurs.

On the basis of low cost, this process should also be considered for welding highly alloyed materials such as stainless steels and high-temperature alloys. Correct selection of welding rod, submerged arc welding composition and welding conditions will very often overcome the weld cracking problems associated with some of these alloyed materials. In many cases, the use of smaller diameter welding rods for multipass welding will eliminate hot-cracking, if encountered, because the narrow stringer beads deposited at higher speeds will cool through the hot-short range more rapidly and better resist thermal contraction stresses.

For example, joints in Type 347 steel aft-frame sections are satisfactorily submerged arc welded with Type 312 rod. The resulting weld metal contains about 5% ferrite which eliminates hot-cracking in this particular fillet weld joining $^1/_8$- to $^1/_2$-in. thick material. Early welding tests where Type 347 stainless steel was welded with Type 347 rod showed hot-cracking mainly because the weld metal was fully austenitic and hot-short under these conditions of high restraint.

The submerged arc process, because of its low cost, should also be considered for building up integral bosses, on the surface of parts, or to provide material for flanges. It should also be considered for surfacing of metals with stainless steel or wear-resistant materials whenever needed. Sigma welding should also be considered for depositing integral bosses and studs as well as for surfacing operations. Despite its apparent greater cost, there are cases where the alloy composition desired in the weld metal may be obtained more readily with sigma welding.

The general rule would be that if welds of satisfactory quality can be made in material of 14-gage thickness or over, the submerged arc process should be recommended because it is the most economical.

To help make the best use of this process for each application, the best possible welding conditions should be established. To accomplish this, the same principal factors should be considered as in the case of sigma welding except that the Unionmelt composition and its sizing should also be considered. Grades N and 50 are normally used for the nickel-base alloys, Grade 80 for the austenitic stainless steels and Grade 50 for thin-gage low-alloy steels. The coarser particle sizing normally gives a deeper and narrower weld than the finer particle sizing. DCRP or alternating current is normally used instead of the DCSP used for Heliarc welding.

SUMMARY

To help choose the correct welding process for any application, the following principal factors should be considered and will serve as a guide:

1. Base metal composition. Some of the more hot-short stainless steels and high-temperature alloys show less hot-cracking when Heliarc or sigma welded than when Unionmelt welded.

2. Thickness of base metal. It is advisable to Heliarc weld material from the thinnest up to about $^3/_{32}$ in. thick, and Unionmelt or sigma weld material about 14-gage and thicker.

3. Production quantities related to apparatus cost and selection, and weld cost. Manually weld small quantities. Semiautomatically or mechanically weld large quantities.

4. Cleaning, grinding and finishing costs.

5. Cost of consumables such as welding electrode, Unionmelt composition, or inert gas.

6. Cost of welding fixtures.

7. Ease of obtaining uniform weld quality in production.

HIGH-TEMPERATURE ALLOYS

Some of the more common stainless steels, such as the 300 series, have been used extensively for jet-engine parts. Other alloys with more specialized properties have been developed by necessity, however, to meet demands for better corrosion resistance and greater strength at high temperatures over a long service period. Table 1 lists the principal alloys that are known to be used; those that are fabricated to the greatest extent are discussed individually. Some applications involve the joining of dissimilar metals because all parts do not have to meet the same requirements of strength at high temperature operation. To use a less expensive or more easily procured metal in certain locations, it may be necessary to weld it satisfactorily to a more highly alloyed material.

In order to help understand the high-temperature alloys more easily, think of them as being divided into three main groups as shown in Table 2.

ACKNOWLEDGMENTS

The author wishes to acknowledge the support of

Table 2

Principal Alloys

Group I

Wrought alloys which are mainly modified austenitic stainless steels. These are usually referred to as superstainless steels. They exhibit high strength at elevated temperatures, mainly as a result of previous strain hardening and age hardening at service temperatures. They are used at temperatures up to about 1100° F depending upon the metal and stress

Group II

Wrought alloys are Ni base, Co base or, if Fe base, usually contain less than 50% iron. Their high strength at elevated temperatures results mainly from aging at service temperatures. These alloys are used at temperatures up to about 1400° F, although some are used for short-time loading at higher temperatures.

Group III

Cast alloys, similar to Group II alloys in composition. Some of these alloys can be used at higher temperatures than those in Group II. Molybdenum can also be included in the group.

Alloys Used in Jet-Engine Components

Alloy	*Nominal composition, %*	*AMS No.*	*Jet-engine component using alloy**	*Logical choice of welding rod*
	Group I—Wrought modified austenitic stainless steels			
19-9 DL	19 Cr, 9 Ni, 1 Mo, 1 W, 0.4 Cb, 0.2 Ti, balance Fe	5526B	Turbine wheels	19-9 DL, 309, 310, 312, 316, 318
Timken 16-25-6	16 Cr, 25 Ni, 6 Mo, balance Fe	5725, 5727	Turbine wheels	Timken 16-25-6, 312, 316, 318, 309, 310, 19-9 WMo, Oxweld 60,† Oxweld 61
Discaloy	13 Cr, 26 Ni, 3 Mo, 1.5 Ti, balance Fe	...	Turbine wheels	Timken 16-25-6, Discaloy
Type 316	18 Cr, 12 Ni, 2.5 Mo, balance Fe	5360	Turbine casings, exhaust cones, afterburners, transition ducts	Type 316 or 318
Type 318	18 Cr, 12 Ni, 2.5 Mo, 1 Cb, balance Fe	...	Turbine casings exhaust cones, afterburners, transition ducts	Type 318
Type 347	19 Cr, 9 Ni, 1 Cb, balance Fe	5362A	Turbine casings, exhaust cones, afterburners, transition ducts	Type 347 or 321
Type 321	19 Cr, 9 Ni, 0.5 Ti, balance Fe	5510D	Turbine casings, exhaust cones, afterburners, transition ducts	Type 321 or 347
Type 310	25 Cr, 20 Ni, balance Fe	5366	Turbine casings, exhaust cones, afterburners, transition ducts	Type 312, 309 19-9 WMo, or 310
Type 304 ELC	18 Cr, 8 Ni, extra low carbon	5511	Turbine casings	Type 304 ELC, Oxweld 61, 347
Type 330	15 Cr, 35 Ni, balance Fe	...	Combustion chambers	Type 309
25-20-2	25 Cr, 20 Ni, 2 No, balance Fe	...	Combustion chambers, exhaust cones	25-20-2, Type 310, 316, 318
	Group II—Wrought specialized alloys			
Multimet alloy—low carbon (or N-155)	20 Cr, 20 Ni, 20 Co, 3 Mo, 2.5 W, 1 Cb, balance Fe	5523B	Nozzle blades, afterburners, exhaust cones, combustion chambers, nozzle diaphragm assembly	Multimet low carbon
S-590	20 Cr, 20 Ni, 20 Co, 4 Mo, 4 W, 4 Cb, balance Fe	5533A	Nozzle blades, afterburners, exhaust cones, combustion chambers, nozzle diaphragm assembly	S-590, Multimet

Alloy	*Nominal composition, %*	*AMS No.*	*Jet-engine component using alloy**	*Logical choice of welding rod*
Refractalloy B	25 Cr, 30 Ni, 8 Mo, balance Fe	...	Combustion chambers, turbine wheels, exhaust cones	Refractalloy B
Refractalloy 26	18 Cr, 37 Ni, 20 Co, 3 Mo, 3 Ti, balance Fe	5760	Turbine wheels	Refractalloy 26
Stellite alloy 33 or Refractalloy 80	20 Cr, 20 Ni, 29 Co, 5 W, 10 Mo, balance Fe	...	Nozzle blades	...
Inconel X	15 Cr, 1 Cb, 2.5 Ti, 0.7 Al, balance Ni	5542B (sheet), 5667B (bars and forgings), 5668B (bars and forgings heat treated)	Combustion chambers, nozzle diaphragm assemblies, exhaust cones, afterburners	Hastelloy alloy W, Inconel, Inconel X, Inconel W
Inconel W	15 Cr, 2.5 Ti, 0.7 Al, balance Ni	...	Combustion chambers, nozzle diaphragm assemblies, exhaust cones, afterburners	Hastelloy alloy W, Inconel X, Inconel W
Nimonic 75	20 Cr, 0.30 Al, 0.40 Ti, balance Ni	...	Combustion liners, exhaust cones, afterburners	Hastelloy alloy W, Nichrome V, Nimonic 75, Inconel Nimonic 80
Nimonic 80	20 Cr, 1 Al, 2.3 Ti, balance Ni	...	Combustion liners, exhaust cones, afterburners	Nimonic 80
Hastelloy alloy B	28 Mo, 5 Fe, balance Ni	5752 (bars and forgings)	Afterburners	Hastelloy alloy W
Hastelloy alloy C	15 Cr, 17 Mo, 4 W, 5 Fe, balance Ni	5530A	Afterburners	Hastelloy alloy W
Hastelloy alloy W	23 Mo, 5 Fe, 5 Cr, balance Ni	...	Afterburners	Hastelloy alloy W
S-186	20 Cr, 20 Ni, 4 Mo, 4 W, 4 Cb, balance Co	5765A (bars and forgings), 5534A (sheet)	Turbine buckets, exhaust cones, afterburners	S-816
Stellite alloy 21 or Vitallium	27 Cr, 3 Ni, 5 Mo, balance Co	...	Combustion chambers, nozzle blades, exhaust cones	Stellite alloy 21
Stellite alloy 25	20 Cr, 10 Ni, 15 W, balance Co	...	Afterburners, exhaust cones	Stellite alloy 25
		Group III—Cast special alloys		
Multimet alloy, medium carbon	20 Cr, 20 Ni, 20 Co, 2 W, 3 Mo, 1 Cb, balance Fe	5767 (precipitation treated), 5768 (precipitation and solution treated)	Turbine buckets	Multimet alloy, low carbon
Stellite alloy 33	20 Cr, 20 Ni, 29 Co, 5 W, 10 Mo, balance Fe	...	Nozzle blades	Multimet alloy, low carbon
S-816	20 Cr, 20 Ni, 4 Mo, 4 W, 4 Cb, balance Co	5675A	Turbine buckets	S-816
Stellite alloy 21	27 Cr, 3 Ni, 5 Mo, balance Co	5385A	Turbine buckets, nozzle blades, power recovery buckets	Stellite alloy 2
Stellite 23	26 Cr, 5.5 W, balance	5375	Turbine buckets	...
Stellite 30	26 Cr, 50 Ni, 6 Mo, balance Co	5380	Turbine buckets	...
Stellite 31	26 Cr, 10 Ni, 7 W, balance Co	5382A	Turbine buckets	...
Stellite 34	High-carbon Stellite 21	...	Turbine buckets	...
Stellite 36	18 Cr, 14 W, 10 Ni, balance Co	...	Turbine buckets	...

* NOTE A: At the present time there is a marked trend toward using lower alloyed metals for specific jet engine parts in order to conserve the scarcer alloying elements. For example, Type 410 martensitic stainless steel (13.5% chromium) is being widely used for components previously made of Group I Cr-Ni alloys. Such parts are located near the forward end of the jet engine where the air enters and is compressed; namely, compressor stators and rotors, and air diffuser assemblies. In the very near future the 410 will displace even more of the Group I Cr-Ni alloys while low-alloy steels such as NAX and Timken 17-22A (S) will replace the 410 which will be used for compressor stators, rotors and air diffuser assemblies, or any other parts that will not be heated over 1000° F.

† "Haynes," "Stellite," "Hastelloy," "Multimet" and "Oxweld" are registered trademarks of Union Carbide and Carbon Corp.

Union Carbide and Carbon Research Laboratories, Inc., the Haynes Stellite Co. and The International Nickel Co., Inc., in supplying some of the data in Table 2 in the appendices.

Comments on welding some of the better known alloys follow.

Appendix

GROUP I—WROUGHT MODIFIED AUSTENITIC STAINLESS STEEL

19-9 DL. This alloy offers excellent weldability and has not exhibited any outstanding difficulty with various welding processes. A filler rod called 19-9 WMo, which is similar in composition to 19-9 DL base metal, has been developed for use in the welding of several dissimilar high-temperature alloys to overcome hot-cracking tendencies.

Timken 16-25-6. This alloy, which has greater amounts of nickel and molybdenum than the usual austenitic stainless steels, occasionally has given trouble with hot-cracking and porosity. However, sound weld metal can be deposited with inert-gas tungsten-arc welding and sigma welding.

Types 316 and 318. The molybdenum-bearing welding rods, such as Types 316 and 318, should be used for welding these base metals to assure adequate strength and corrosion resistance at high temperatures.

Features of Welding Processes Used in Jet-Engine Work

	Apparatus investment costs	*Maintenance costs*	*Range of application*	*Power supply problems encountered*	*Portability of equipment*	*Weld grinding and finishing*	*Oxide scale on welds*	*Weld metal control*	*Spatter—slag loss*	*Control of joint build-up*	*Control of penetration*	*Continuity of operation*	*Welding speed*
Resistance	High	High	Low	High	Low	...	...	...	...	...	...	...	...
Heliarc	Low	Low	High	Few	High	Low	Low, none	High	None	High	High	High	...
Flux-coated metal arc	Low	...	Low	Few	High	...	High	...	High	...	...	...	...
Sigma:													
Manual	...	Low	Low	Few	High	Low	Low, none	High	None	High	High	High	High
Mechanized	...	Low	Low	Low	Low	Low	Low, none	High	None	High	High	High	High
Unionmelt:													
Manual	...	Low	Low	Few	High	Low	None	High	None	High	High	High	High
Mechanized	...	Low	Low	Few	Low	Low	None	High	None	High	High	High	High

Types 347 and 321. Type 347 or Oxweld 60 rod is recommended for welding these alloys to provide adequate strength and corrosion resistance at elevated temperatures.

Type 310. In welding thicker sections of this alloy, Types 312, 309 or 19–9 WMo rod are preferred to Type 310 rod in order to overcome a tendency toward hot-cracking, which is sometimes present with this alloy in rigidly restrained weldments. The use of DCSP for tungsten-arc welding and DCRP for sigma and DCRP or ac for Unionmelt welding with stringer bead techniques are also recommended to help relieve hot-cracking.

Type 304 ELC. This alloy has excellent weldability with any of the welding rods indicated for it in Table 2.

Type 330. The hot-shortness of this high-nickel alloy suggests the use of the lower nickel Type 309 welding rod with DCSP and stringer bead techniques for tungsten-arc welding, DCRP for sigma and DCRP and ac for Unionmelt welding.

25-20-2. This particular alloy is used normally in sheet form and should be welded with the tungsten-arc process using DCSP.

Table 3—Logical Choice of Welding Rod* for Joining Dissimilar Metal Combinations

Base Metal	*Welding rod*
Type 410 to Inconel W and X	Inconel, Types 309, 310 and 312
Type 347 and 310 to Multimet alloy	Multimet alloy, Hastelloy alloy W, Types 312, 309 and 310
Type 310 to Stellite alloy 21, blades	Hastelloy alloy W, Types 312, 309 and 310
Inconel to Hastelloy alloy C	Nickel and Inconel
Inconex X to Stellite alloy 21	Inconel, Hastelloy alloy W, Types 312, 309 and 310
Type 410 to 310, 321 or 347	312, 309, 310 or Inconel
Type 410 to 304	304 and 410
Hastelloy alloy B to C	Hastelloy alloy W
Inconel W or X to Hastelloy alloys B and C	Hastelloy alloy W
S-816 to Timken 16-25-6	Hastelloy alloy W or Types 316, 318, Inconel
Timken	
16-25-6 to Stellite alloy 30	Inconel Hastelloy alloy W
16-25-6 to Stellite alloy 21	Inconel Hastelloy alloy W, Timken 16-25-6, Type 312
16-25-6 to Hastelloy alloy C	Inconel, Hastelloy alloy W, 19–9 DL, Types 312, 316 and 318
19–9 DL to Stellite alloy 30	Hastelloy alloy W, Inconel, Types 312, 316, 318, 309, 19–9 WMo and 310
S-816 to Type 501	Inconel, Type 312, 316, 318, 16-25-6, 309 and 310
16-25-6 to Type 501	Hastelloy alloy W, Inconel, Type 312, 309, 316, 318, 310 and 16-25-6
16-25-6 to 4340	316 ELC, 318, Multimet (low-carbon), 316, 309 and 312
Multimet alloy to Type 316	Hastelloy alloy W
Multimet alloy to Stellite alloy 23 and 30	

* The rod selection sometimes varies for different welding processes.

GROUP II—WROUGHT SPECIALIZED ALLOYS

Multimet Alloy (Low-Carbon, N-155). This alloy tends to be hot-short above 1800° F during welding. Hot-short cracks about $^1/_8$ in. long sometimes form in the base metal next to and perpendicular to the weld. Experiments with welding speed and jigging may be necessary to minimize hot-cracking in the welding of this sheet material.

S-590. The higher columbium and tungsten content of this alloy (compared to Multimet) may give even more difficulty than Multimet in respect to hot-cracking with all welding processes.

Refractalloy B. The high-nickel content of this alloy requires narrow stringer beads or multipass techniques to avoid hot-cracking.

Refractalloy 26. This alloy presents the same welding problems as those associated with Refractalloy B.

Inconel X. This alloy has given considerable trouble with all welding processes when welded in the age-hardened condition. Extensive cracking has occurred in the base metal next to the weld as well as in the weld metal. This alloy should be welded only in the annealed condition. A welding rod such as Hastelloy alloy W or Inconel is recommended in preference to the Inconel X or Inconel W rod to give a slightly more ductile weld metal and thus to help prevent weld cracking.

Inconel W. This metal has slightly lower strength but better ductility than Inconel X, and has given considerably less trouble in the weld, or in the base metal next to the weld, compared to Inconel X.

Nimonic 75 and 80. These alloys are high in nickel and generally require a higher gas flow than the usual austenitic stainless steels during tungsten-arc welding. An argon flow of about 25 cfh is recommended to minimize formation of porosity.

Hastelloy Alloys B and C. These alloys also have a tendency toward porosity in tungsten-arc welding because of their high nickel and molybdenum contents. They should be welded with a higher-than-normal argon flow rate, about 25 cfh.

S-816. This material may give some trouble with hot-cracking in sheet form because of its high tungsten and columbium contents. It is suggested that the same precautions be followed as in the case of Multimet.

Stellite No. 25. This alloy compares to Multimet alloy with respect to hot-cracking in the base metal next to the weld. The same methods apply for overcoming the hot-cracking tendency.

General Comments. Trouble shooting on all alloys in Groups I and II can be summarized as follows, with respect, particularly, to hot-cracking.

1. Use a welding technique that will produce a weld as narrow as possible, thereby holding expansion and contraction stresses to a minimum.
2. Select a welding speed that also restricts expansion and contraction stresses. Usually this can be done only by trial and error because of the individual characteristics found in the combinations of joint types and alloys.
3. Use DCSP for Heliarc, DCRP for sigma and Unionmelt, and stringer bead techniques for most reliable results.

GROUP III—CAST SPECIAL ALLOYS

Most of these alloys have poor weldability. If it is necessary to weld them, they should be preheated and welded with the narrow stringer bead technique, or the multipass technique, and then slowly cooled after welding. Special sequence of welding will also be required in most cases. Intermittent short welds are made on opposite sides or at specially located positions to reduce distortion and stresses.

WELDING DISSIMILAR METALS

Table 3 lists various combinations of dissimilar alloys and recommends the welding rods that can be expected to offer best results. These rod selections are based on experience in those cases where successful results were obtained. Other selections are suggested by analysis of metallurgical needs as well as the welding techniques used. Rod selections are listed in Table 3 in the order that the rods may be tried experimentally before a final choice is made. Hastelloy alloy W, Inconel, Type 312 stainless steel and 19–9 WMo rods seem to be good choices for most of the base metal combinations shown; it would appear that first trials should be made with one or more of these rods.

Vacuum Tightness of Welded and Brazed Aluminum Containers

Tests of tightness of welded and brazed aluminum containers together with a description of the welding and brazing methods used

by Mike A. Miller and Allen S. Russell

Summary

Welded and brazed aluminum containers especially prepared with butt and perpendicular joints have been tested for vacuum tightness. The methods of welding and brazing have been described. Most of the gas that appeared in the vacuum system during test was evolved from the sorbed film originally on the metal. When the part of this sorbed gas, which was condensable at −78° C, was removed from the measuring system, the rate of appearance of gas for a properly welded or brazed container of the dimensions used in these tests was less than 2×10^{-5} ml STP/hr.

INTRODUCTION

THERE is practically no information in the literature on the vacuum tightness of welded or brazed aluminum joints. In fact, such misconceptions exist as to the permeability of these joints to air, that the ability of welded or brazed aluminum joints to maintain a high vacuum has been doubted.

The vacuum tightness of containers can be determined most easily with mass spectroscope-type leak testing devices. However, inasmuch as one purpose of the present work was to determine the relative importance of outgassing of the sorptive surface film on the apparent leakage rate, the measurements were made by sealing test containers onto a high vacuum system. In order to remove as much sorbed gas as possible from them before the test, the containers were first heated and evacuated and then cooled to dry ice temperature to reduce the vapor pressure of any remaining impurities on the surface. A General Electric type H (Freon-sensitive) leak detector, which is useful in locating major leaks in imperfect containers, showed no leaks in any of the containers reported here.

Wrought aluminum is thought to be impervious to gases at room temperature. Hydrogen, however, is the only gas for which accurate diffusion rates have been measured. The data of Smithells and Ransley[1] and of Russell[2] show the diffusion rate of hydrogen at 1 atm pressure to be immeasurably small at temperatures much below 250° C. The diffusion rate for clean aluminum is only about 1×10^{-7} (ml STP) (mm thickness) / (sq cm area) (sec) for 1 atm pressure at 500° C. Even this value decreases rapidly on continued heating of the sample. The diffusion rate of hydrogen through the oxide film on aluminum is much less than that through the pure metal.

Hydrogen is the only gas that is appreciably soluble in aluminum. The solubility of hydrogen has been determined by Ransley and Neufeld[3] to be of the order of 0.04 ml STP/100 g in solid aluminum and 0.7 ml STP/100 g in liquid aluminum at 1 atm and at the melting point, 660° C.

Aluminum in common with other metals is apt to hold a sorbed film—largely water—on its surface or surface oxide. Keller and Edwards[4] reported that 2S aluminum exposed outdoors for 10 months held about 0.3 ml STP of water vapor and gas per square centimeter of metal area. For the containers of the present investigation, almost 100 ml STP of gas would have been sorbed during such exposure. This film can be removed by heating in vacuum. Below about 300° C sorbed water is evacuated without appreciable decomposition, but at higher temperatures the water is apt to react to form aluminum oxide and give off hydrogen.

PREPARATION OF SPECIMENS

The vacuum system consisted essentially of a mercury diffusion pump, McLeod gage to measure pressure, provision for attaching by deKhotinsky cement the container to be tested, and mercury cutoffs between the elements. No stopcocks were employed. The volume of the system up to the mercury cutoff to the vacuum pump, including the volume of the test container, was 1025 ml.

The test containers were designed to evaluate a considerable length of several types of joints. Each of the four welded containers had a longitudinal butt weld to form the cylindrical body, two circumferential

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corner welds for the end plates and a fillet weld joining the exhaust tube to the top end plate. The dimensions of the welded containers, which were of Alcoa 3S aluminum, and the order in which the welds were made are shown in Fig. 1. Filler wire was of Alcoa 2S aluminum. All the welding was done by the argon-shielded tungsten arc process using a 200-amp a-c welder equipped with a Linde HW-4 torch. A $^3/_{32}$-in diameter electrode was used for welds Nos. 1, 2 and 3, and a $^1/_{16}$-in. diameter electrode for weld No. 4 on all containers tested. The arc was initiated by a high-voltage, high-frequency spark. The welding current was 70 amp for weld No. 1, 60 amp for welds Nos. 2 and 3 and 50 amp for weld No. 4. Prior to welding, all parts were degreased with carbon tetrachloride, etched in 5% sodium hydroxide solution followed by a dip in 50% nitric acid solution, thoroughly rinsed and dried. The inner surfaces of the container were not touched after cleaning.

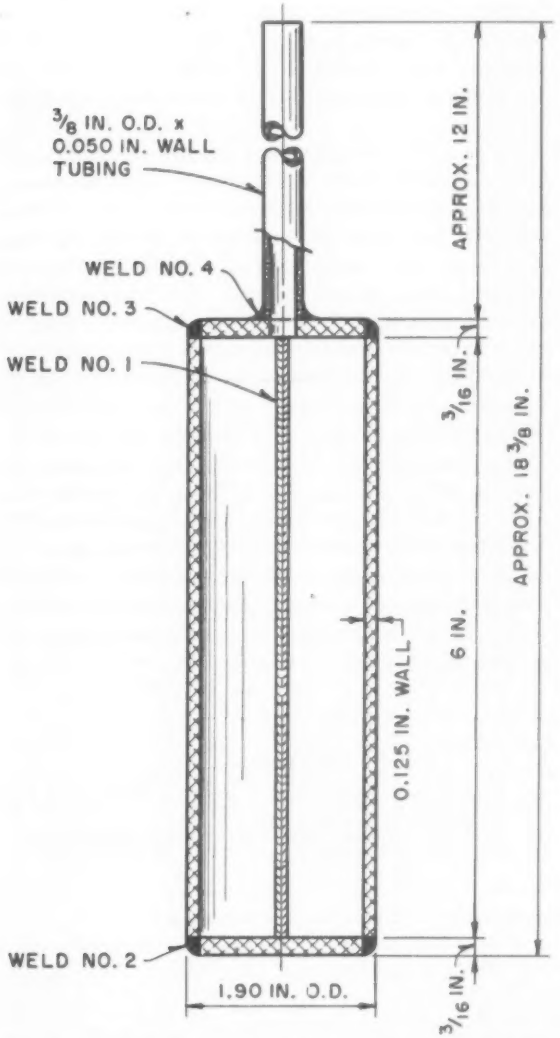

Fig. 1. Welded 3S container for vacuum testing (after welding)

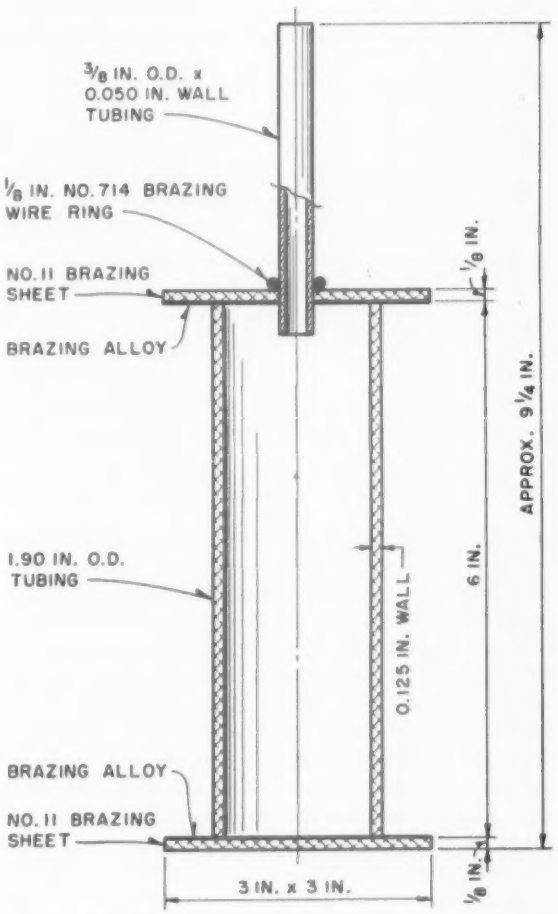

Fig. 2. Brazed 3S container for vacuum testing (before brazing)

In addition to the welded containers, it was considered of interest to test several brazed containers. The dimensions and method of assembly of these brazed containers, which were of Alcoa 3S aluminum, are shown in Fig 2. After degreasing with carbon tetrachloride, all parts were etched in 5% sodium hydroxide solution, dipped in 50% nitric acid solution, rinsed and dried. The No. 11 brazing sheet surfaces, the abutting ends of the tubular section and the No. 714 brazing wire were coated with a methanol paste of Alcoa No. 34 brazing flux. After oven drying, the assembled parts were brazed at 1120° F. The brazing flux was removed by washing in hot water, soaking in hot 50% nitric acid solution, rinsing in hot water and oven drying. A 12-in. length of $^3/_8$-in. diameter Alcoa 3S tubing was butt welded to the 3.5-in. exhaust tube by the argon-shielded tungsten arc process to permit easier handling in the vacuum apparatus.

RESULTS AND DISCUSSION

The results of the vacuum tests with the four welded containers are summarized in Tables 1 and 2. As

Table 1—Effect of Outgassing on Pressure Build-Up in Evacuated Welded Aluminum Container

Container No.	Evacuation Duration, hr	Evacuation Temp., °C	Evacuation Pressure, mm Hg	Temp., °C	Pressure, mm Hg, at temperature: 1 hr	10 hr	100 hr	Pressure, mm Hg, test at −78° C: 1 hr	10 hr	100 hr
W-1	2	400	0.5×10^{-6}	25	12×10^{-4}	.....	.....	4×10^{-4}	.....	.....
W-1	2	400	2.0×10^{-6}	25	3×10^{-4}	(8×10^{-3})	9×10^{-2}	1×10^{-4}	5×10^{-4}	30×10^{-4}
W-1	2	400	1.0×10^{-6}	300	1×10^{-4}	1×10^{-2}	20×10^{-2}	.....	5×10^{-4}	90×10^{-4}
W-1	2	460	0.3×10^{-6}	25	1×10^{-4}	10×10^{-4}	.....	.....	6×10^{-4}	.....
W-1	2	500	0.8×10^{-6}	25	.....	20×10^{-4}	11×10^{-2}	.....	10×10^{-4}	39×10^{-4}

Table 2—Summary of Pressure Build-Up in Evacuated Welded Aluminum Containers

Container No.	Evacuation Duration, hr	Evacuation Temp., °C	Evacuation Pressure, mm Hg	Temp., °C	Pressure increase, mm Hg, Test at temperature: 1 hr	10 hr	100 hr	Test at −78° C: 10 hr	100 hr
W-2	15 5	25 450	3×10^{-6} 2×10^{-6}	25	.....	5×10^{-4}	26×10^{-4}	4×10^{-4}	21×10^{-4}
W-3	1 16	25 240–300	16×10^{-4} 1×10^{-6}	25	1.4×10^{-4}	10×10^{-4}	10×10^{-2}	6×10^{-4}	50×10^{-4}
W-4	15	25 450	5×10^{-6} 4×10^{-6}	25	2.5×10^{-5}	1.1×10^{-4}	10×10^{-4}	1×10^{-4}	7×10^{-4}

shown in Table 1, container W-1 was evacuated and tested under several conditions. After heating all of container W-1, except the joint to the vacuum system, at 400° C, at a measured pressure of 5×10^{-5} mm of mercury it was cooled to room temperature, shut off from the vacuum pump and the pressure of the gas collected after 1 hr measured as 12×10^{-4} mm of mercury. Even at this low rate of collection, most of the gas must have come from the sorbed film, since the pressure was reduced to 4×10^{-4} mm of mercury when the container was cooled in a dry ice–acetone bath (−78° C) which would condense out water and possibly cause the resorption of carbon dioxide. Most of the remaining air was probably derived from the sorbed film.

After the above tests, the vacuum was broken and the container was exposed to room air. After reheating for 2 hr at 400° C at a pressure of 2×10^{-4} mm of mercury, tests at room temperature showed a linear increase in pressure of 9×10^{-4} mm of mercury per hour. Much of this was caused by water vapor and when the sample was immersed in the dry-ice bath the pressure in the system increased at a rate of 3×10^{-5} mm per hour, a value about one-tenth as high as after the first outgassing.

The rate of total gas collection was roughly twice as high when the sample stood at 300° C as at 25° C, while the ratio was three times as high for the gas which was not condensed at −78° C.

Increasing the temperature during evacuation to 460° C resulted in a tenfold decrease in the total gas collection rate at room temperature, but the noncondensable gas rate at room temperature remained essentially constant. A further increase in the temperature of evacuation to 500° C led to increases in the rates of collection at room temperature of both condensable gases and air. This extreme heating under vacuum caused partial collapse of the test container which may have developed a leak in one of the welds.

Somewhat lower pressure build-ups were obtained in containers W-2 and W-4 (Table 2), which were outgassed 15 hr at room temperature and then 5 hr at 450° C. Container W-3, which had less rigorous outgassing, had correspondingly higher rates of gas collection from its sorbed film. For container W-4, the noncondensable gas rate was 7×10^{-4} mm of mercury in 100 hr at room temperature, equivalent to less than 1×10^{-5} ml STP/hr. Even this value includes some gas from the sorbed film and from reaction of outgassing water with the aluminum surface.

The results of tests with two brazed containers are given in Table 3. The best of these containers, B-1, compared favorably in vacuum tightness with the best of the welded containers, W-4. There would appear to be no fundamental reason why properly designed brazed aluminum containers should not perform equally as well as properly welded aluminum containers, and the present results serve to verify this.

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Table 3—Summary of Pressure Build-Up in Evacuated Brazed Aluminum Containers

Container No.	Evacuation Duration, hr	Evacuation Temp., °C	Evacuation Pressure, mm Hg	Pressure increase, mm Hg, Test at 25° C: 1 hr	50 hr	100 hr	Test at −78° C: 1 hr	50 hr	100 hr
B-1	39 5	25 450	2×10^{-6} 2.5×10^{-6}	12×10^{-4}	10.5×10^{-4}	16×10^{-4}	.....	10×10^{-4}	14×10^{-4}
B-2	19 5	25 450	22×10^{-6} 4×10^{-6}	6×10^{-4}	4×10^{-3}	.....	3×10^{-4}	3×10^{-3}	.....

Selection and Evaluation of Methods of Hard Facing

Major methods of application of hard-facing materials with particular emphasis on the inert-gas-shielded arc methods

by J. J. Barry

INTRODUCTION

CONSISTENTLY predictable results are enjoyed every day by users of the hard-facing process for providing wear resistance to a great variety of both new and used equipment and mechanical parts. These results are gained by following methods and procedures based on more than thirty years of accumulated mechanical and metallurgical experience in the "wear-resisting" field.

Basically, hardfacing is a process through which an alloy material is welded to a metal part forming a protective surface which resists abrasion, heat, impact, corrosion and erosion or any combination of these wear factors. While the initial pioneering for this process may be over, extremely significant advances continue to refine and extend its applications. Technological progress in this field, as in others, is virtually perpetual.

Comparatively recent developments in methods of applying hard metals—such as the nonconsuming and consuming electrode forms of inert-gas-shielded arc welding—present additional possibilities of choice (for maximum economies and greater effectiveness)—to users of the basic hard-facing process.

The importance of understanding the nature of the wearing conditions on the part, along with a corresponding understanding of the qualities and functions of the various types of hard-facing material, has been substantially treated and emphasized in our trade literature. The range of possible service requirements is pretty well known. Moreover, the range of possible overlays to meet these service requirements is a large one. We know that no one hard metal is suitable for the hundreds of different applications encountered in industry. We know also that proper selection of the area to be hard faced is just as important as the alloy used.

Today we can assume that the science of selecting hard metals is known and observed—subject, of course, to continual refinements. This has been no small accomplishment, particularly in view of the fact that the properties of modern hard-facing materials cover a wide range of variations. There are almost indistinguishable gradations between various materials, from the harder and tougher materials among standard hard-facing electrodes and rods to solid inserts of tungsten carbide, and to wear-resistant materials that are scarcely "hard" at all, such as bronzes and brasses.

WELDING METHODS OF APPLYING HARD-FACING MATERIALS

If present and potential users are to take advantage of the maximum effectiveness and economies of the hard-facing process, the proper selection of the *method of application* can be as important as the proper selection of the material for the deposit. Inefficiencies are often concealed by results which are satisfactory but do not represent the best operating economics, nor do they impart to the part the maximum service life obtainable. Extra service life and economies can be obtained by selecting the proper method of application. In this paper, several major methods of application will be discussed with particular emphasis on two inert-gas-shielded arc methods: the nonconsuming and consuming electrode forms.

These two methods are showing spectacular success in the application of hard metals, particularly when used automatically. They offer a wider choice for users who have been employing the oxy-acetylene, electric arc, carbon arc and the atomic hydrogen methods. Two other basic electric arc methods—the submerged and open arc techniques—are also speeding up hard-facing applications to meet the increased production and quality requirements of modern industry.

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DEFINITION OF HARD-FACING MATERIALS

Before we proceed to some of the values inherent in the use of various methods of applying hard-facing materials, we would like to establish a working definition of these materials. In its broadest aspect, hard facing as a process comprehends the maintenance of surface dimensions against the effects of wear. Our definition of hard-facing materials includes all metals applied to the surface of another metal, whether it be similar or dissimilar, for the purpose of resisting some form of wear. For example, the use of aluminum bronze as a protective overlay on plain carbon steel is not strictly "hard" facing, but it is used for surface protection against wear, and it does lend itself effectively to certain deposition methods for providing wear resistance which are the primary concern of this paper.

When we discuss hard-facing materials we should not be influenced too much by the word "hard." It is an established metallurgical fact that high hardness is not necessarily a criterion for good abrasion resistance. The Rockwell or Brinell hardness number is not necessarily an index to the wear-resistant properties of a hard-facing deposit.

Broadly defined, then, hard-facing operations often involve materials for overlay work where hardness is not the primary characteristic required. Indeed, it is only in meeting problems of pure abrasion that hardness itself (although not always) is the most important characteristic of the hard-facing alloy.

THE OXY-ACETYLENE METHOD

With each method of applying hard-facing materials it is to be assumed that the most efficient operating procedures are observed and practiced; it is only then that the different values inherent in the efficient use of each method can be enjoyed by the user.

In the early days of welding when the value of hard facing with various alloys was first recognized, the oxy-acetylene welding process was used primarily. This method ordinarily produces the best quality deposits with the least amount of porosity, cracks and dilution with the base metal.

Oxy-acetylene application is preferred when a thin overlay of metal is required. It is especially suitable for precision motor parts because of the close control over the molten metal. It is very good for valve jobs on which a cobalt base material is used. The deposit can be put down very smoothly. Figure 1 shows an operator restoring the seat of an exhaust valve by the oxy-acetylene method.

The reclaiming of Diesel engine valves, involving the application of a hard-facing alloy to the worn seat, is an excellent example of the proper use of the oxy-acetylene hard-facing method.

The first step in reclaiming consists of cleaning the valves thoroughly. Then the hard-facing alloy is

Fig. 1 Restoring exhaust valves by oxy-acetylene method

applied to the worn seat. A carburizing flame is used and is kept pointed away from the stem to avoid distortion. Then the valve is centered in a lathe, the outside of the valve is trued up and the seat machined to size. Finally the seat is finished in a valve-grinding machine.

These reclaimed valves, measuring from 4 to $5^1/_4$ in. in diameter, have a service life of three to four times that of new valves.

In general, particles of scale and foreign matter are eliminated more easily by the oxy-acetylene method, and edges and corners can be formed readily. This is particularly important when grinding the part to a finished dimension is necessary. In many cases, especially in the field, the electric arc method is not readily available, whereas the oxy-acetylene method is more portable. Figure 2 shows the repair of a tamping bar in the field.

Application of hard-facing material by the oxy-acetylene method to cutter bits, sprocket teeth, clutch jaws, chains, worm gears and cutter-bar ends is very effective. On the other hand, teeth, blades and other parts of heavy road machinery and earth-moving equipment, which wears rapidly when made of unhardened steel, are effectively hard faced by the electric arc method.

THE ELECTRIC ARC METHOD

While both the oxy-acetylene and electric arc

Fig. 2 Railroad tamping bars being restored by oxy-acetylene method

methods of application are effectively used on a wide range of metals—low- and medium-carbon steels, high-carbon steel, low-alloy steel, stainless steel, cast iron, malleable cast iron—the particular requirement of each job will clearly indicate the use of one method over the other. On manganese steel, incidentally, the electric arc method only is recommended. Typical parts include crusher jaws and dredge cutter blades.

Electric arc application is advantageous for large areas over irregularly worn surfaces, or where a fine finish or precision dimensioning is not necessary. Speed of deposition is greatly accelerated over the oxy-acetylene method. It should be remembered, however, that the single layer deposit by the arc method tends to result in a deposit somewhat diluted with the base metal, softening the deposit and reducing its resistance to abrasive wear. The dilution effect can be minimized by depositing a thin first layer followed by a second layer thick enough to restore the worn part to its original dimensions. In general, the arc method is particularly suitable for hard facing all heavy parts where exceptionally thin, smooth deposits are not *required*. Figures 3, 4 and 5 show the repair, build-up and hard facing of steel mill equipment by the electric arc method.

In hard-facing cast iron, less difficulty is encountered with the electric arc than with the oxy-acetylene flame because of the extremely high temperature of the arc. This high temperature releases the impurities and usually melts out the surface porosity of the cast iron.

For hard-facing excessively worn parts, although many successful applications are made with oxy-acetylene, the arc process should be used whenever possible to build up the worn area to within $^1/_4$ in. of the finished dimension. As a rule (general), actual hard-facing deposits strictly defined should be restricted to $^1/_4$ in. or less.

A good example of the type of job requiring build-up by electric arc deposition—followed by an application of hard-facing material—is the huge bucket of a

Fig. 3 Arc deposition on a slabbing mill pinion gear

Fig. 4 Depositing alloy on the stem of a gas-engine valve. Electric arc method

Fig. 5 Building up wobblers and coupling boxes, electric arc method

Fig. 6 Electric arc application of hardfacing material to dipper teeth

power shovel. A typical bucket is 6 ft wide with manganese steel teeth, lip, edges and tooth sockets.

The excessively worn areas are built up with manganese electrodes. Then the built-up teeth, bucket lip, edges, as well as tooth sockets, are hard faced with an appropriate alloy. Figure 6 shows the hard facing of bucket teeth and lips by the electric arc method.

SUBMERGED AND OPEN ARC METHODS

The increased production requirements of modern industry call for continuous hard-facing techniques. In this connection the submerged and open arc methods help to speed up operations by both manual and automatic means.

Automatic submerged arc welding is effectively used to build up worn cylindrical parts such as shafts, rods, plungers, rolls, roll necks, etc. A typical setup for submerged arc welding involves a machine lathe which turns the work to be overlayed with weld metal, and a lathe carriage which carries the welding wire feeding mechanism and the flux hopper in a lateral direction as the round is turned in the lathe.

The operation is the same as a machining operation, except that the welding arc (completely submerged under flux) replaces the cutting tool. The welding wire is uncoated and fed by wire feed rollers driven by a wire feed motor. A typical automatic submerged arc hard-facing application is shown in Fig. 7.

This technique opens a new field for the hard-facing process because the high deposition rate possible makes the application very economical, whereas the lower deposition rate of manual welding combined with higher electrode costs renders many manual applications uneconomical.

The gap between fully automatic arc welding and manual welding is rather successfully bridged by manually operated submerged-arc welding machines. Units of this type are portable with a cable connected to the electrode which is held in the operator's hand. Deposition rates and weld quality are equal to the automatic arc process, while the cost per pound of deposit is generally slightly higher.

The open arc method employs no flux except as a coating on the wire or within the sheath of fabricated wires, which are used instead of the "stick" that characterizes the basic electric arc process. The coated and fabricated wire produce good quality weld metal, but the deposition rate is limited (as in manual arc welding), by the arc characteristics.

CARBON ARC AND ATOMIC HYDROGEN METHODS

Although the carbon-arc process is usable on metals which can be hard faced by either the oxy-acetylene or electric arc methods, deposits generally do not exhibit the hardness properties obtainable with the two more common methods.

The carbon arc is particularly good for general-purpose-bearing metal deposits. For those jobs where access to the weld area is difficult (as in narrow valve openings) this offers the high degree of maneuverability required.

The atomic hydrogen method is used extensively in

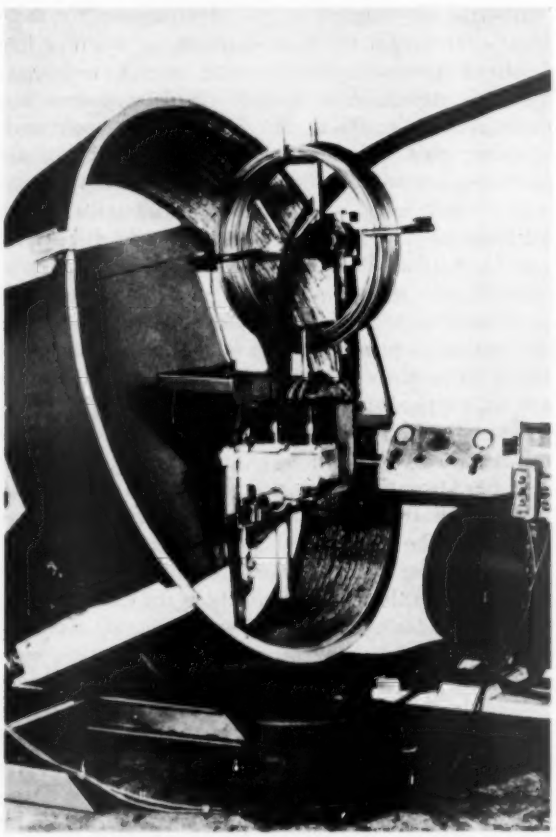

Fig. 7 Hard facing a grinding ring by the submerged arc process

oil fields for tipping rotary bits with tungsten carbide. It is even softer than the oxy-acetylene flame and does not have the penetration of the electric arc. For "touch-and-go" work with hard-facing materials, this method is recommended. It offers good quality deposits, but a slow deposition rate and a high gas consumption make it expensive.

THE INERT-GAS-SHIELDED METHOD—NON-CONSUMING ELECTRODE

This method offers a happy medium between the oxy-acetylene and electric arc methods. Deposits have substantially less dilution with the base metal than conventional electric arc deposits, but slightly more than oxy-acetylene deposits. It will produce less distortion than the oxy-acetylene method because the rate of heat input is more rapid. It produces deposits of substantially higher hardness and lower penetration than those produced by the basic electric arc method.

When applied manually, a rod is hand-fed into the molten puddle created by the nonconsuming electrode in an atmosphere shielded by the inert gas. The backhand welding technique is effective for hard facing small sections or parts of mild steel. This technique produces maximum weld hardness and minimum penetration of the deposit into the base metal, thus approaching conditions obtained with the oxy-acetylene method.

With forehand welding, deposition rates are more than two times faster than those obtained with electric arc welding, and the deposit quality is superior to conventional arc deposits. Forehand welding is recommended for hard facing massive parts or large areas because of the high deposition rates possible with good quality.

An extremely significant trend in connection with this method is the development of equipment designed for automatic applications.

AUTOMATIC HARD FACING OF TOOL JOINTS WITH TUNGSTEN CARBIDE

A relatively new automatic method, employing the inert-gas-shield with nonconsuming electrode, is very efficient when applied to heavy sections, such as tool joints on oil well drill pipe. (*Note:* This method is also satisfactory for facing thin edges.) A photograph of the test setup employed for this operation is shown in Fig. 8.

These drill pipes, made up in sections about 40 ft long and coupled by a tapered thread connection, extend to the depth of the hole which, in some cases, runs up to three miles. The couplings or tool joints are subjected to severe earth and rock abrasion against the sides of the holes.

When the use of tungsten carbide for extreme abrasive service became widespread, oxy-acetylene welding was used to apply it. However, this method was too slow for the large number of joints being reclaimed.

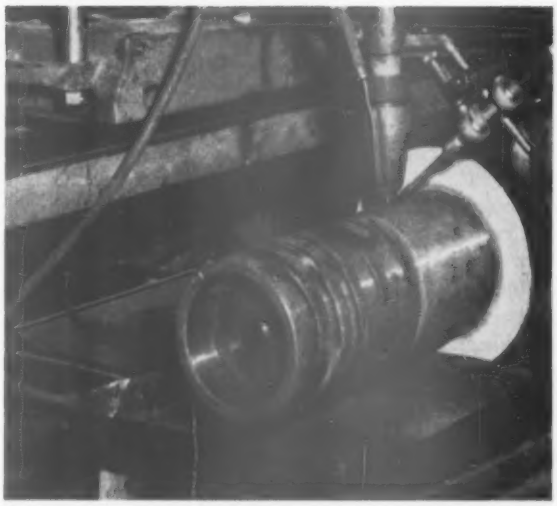

Fig. 8 Test arrangement for hard-surfacing tool joint with tungsten carbide

The next step was arc welding with electrodes of the "stick" variety. Automatic submerged arc welding was next in line and is still widely practiced. This method, however, results in the solution of some of the tungsten carbide into the base material, making it very crack-sensitive for subsequent heat-treating operations.

Tungsten carbide has demonstrated conclusively its superior resistance to earth abrasion. The one difficulty associated with all the present arc welding methods of applying tungsten material is that the carbide particles are completely or partially dissolved by the molten steel and high temperature of the arc. The inert-gas-shielded method, employing a nonconsuming electrode, is proving itself efficient in keeping the carbide particles in the base metal. This ideal condition also greatly enhances the success of heat treatment of the tool joints after hard-facing operations.

Fig. 9 Carbide feeding on a tool joint with arc

In this particular application, the inert-gas-shielded arc is used simply to melt the base metal, producing an elongated molten pool. The carbide particles are then sprinkled into the molten pool behind the arc as shown in Fig. 9. The molten metal then freezes around the carbide particles and locks them in as shown in Fig. 10.

The rate of feed for the carbide particles is controlled electrically through a vibrating hopper. The size of the carbide particles is 30–40 mesh. These give the best distribution through the weld bead. The tungsten carbide particles are shown in Fig. 11 feeding onto the tool joint without an arc being struck. Metallographic specimens, Fig. 12, show an optimum alloying between the carbide and the matrix, as illustrated by a narrow white border on the carbide particles.

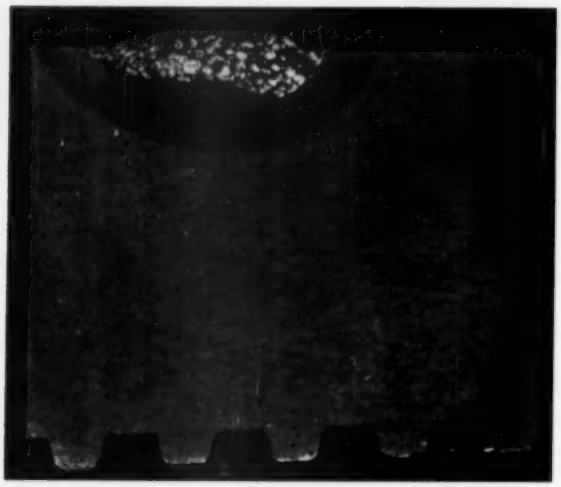

Fig. 10 Section of a single bead deposit showing good carbide distribution. × 3

Fig. 11 Details showing correct adjustment for carbide feeding on a tool joint

Abrasion tests on hard-facing deposits made by this method indicate that resistance is comparable to that obtained by the oxy-acetylene method and better than any of the results for arc-welded deposits. An abrasion test specimen is shown in Fig. 13. There is no cracking and only minor porosity. The hardness of the matrix ranges between 48–51 Rockwell "C". These values

Fig. 12 Photomicrographs of bead deposit

(Above) 40-120 mesh tungsten carbide particles in a NE8645 matrix × 75. *(Below)* × 500 Microhardness: VPN, 25 g load: skeletal eutectic 658, 636, 704; light-etching acicular phase 528, 512, 578; dark etching acicular phase 561, 616, 528. Etchant: Villella's picric-hydrochloric acids.

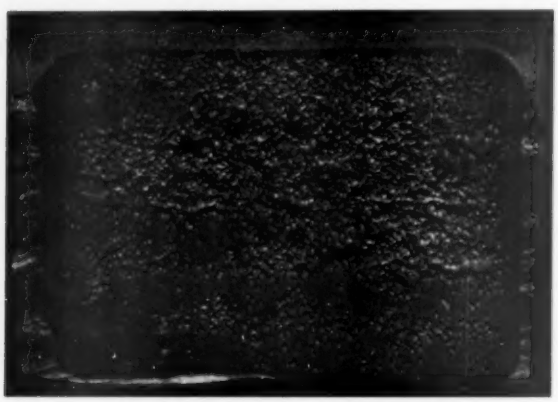

Fig. 13 Abrasion test specimen

are midway between the optimum hardness for toughness and abrasion resistance.

Comparison of this method of hard facing with tungsten carbide on tool joints with that of manual welding with electrodes shows considerably better abrasion resistance. There is more efficient carbide distribution, less enrichment of the matrix with carbon and tungsten and less cracking. The increase in abrasion resistance over arc deposits is more than doubled.

Another advantage over both gas and arc operation is that it uses loose granular carbide, while a fabricated rod is required by other methods. It can be deposited many times faster than the gas welding method. It is automatic in operation, of course, while oxy-acetylene deposits must be made manually.

All these advantages depend naturally on an appropriate adjustment of controlling factors in the procedure. Figure 14 shows the automatic equipment used in the operation.

In general, this new automatic method of hard facing with tungsten carbide is as fast as present arc hard-facing methods—but the quality of the product for abrasion resistance is comparable with oxy-acetylene welded deposits.

THE INERT-GAS-SHIELDED METHOD—CONSUMING ELECTRODE

The other major inert-gas-shielded arc method for applying hard-facing material involves the use of a consumable electrode in the form of wire which is fed automatically into the protected arc stream. The wire is bare in coil form, carrying heavy currents on relatively small diameters. The composition of the wire electrode is varied, of course, to meet the job requirements.

Fig. 14 Automatic Heliweld Head which provides for arc starting without high frequency

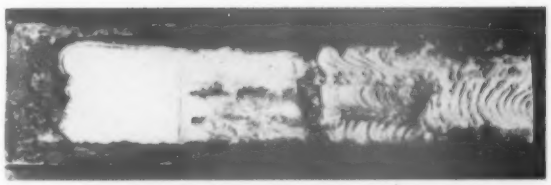

Fig. 15 One-, two- and three-pass aluminum-bronze overlay on 3/4-in. steel plate. Note smooth, spatter-free deposit and low penetration

This method, applied manually with a gun or automatically with a head, offers hard-facing advantages which are inherent in the speed of application. The development and production of hard facing wires, and wires composed of softer alloys, are the keys to the growing use of this method, particularly on build-up and surfacing work of a volume, repetitive nature.

Currently, overlays of aluminum bronze on dissimilar metals such as steel, copper, cast iron and manganese bronze are effectively made with this method. These overlays are semihard, durable and corrosion resistant. Figure 15 shows a one-, two- and three-layer aluminum-bronze overlay on steel plate. Figure 16 shows the microstructure of an Aircomatic aluminum-bronze deposit on steel.

An important application for this method is represented by steel mill guides. These guides require a soft build-up, yet one which will have reasonable durability. Phosphor bronze or aluminum bronze is effectively used by this method. The conventional electric arc method requires chipping, grinding and considerable finishing work. But with this method the aluminum bronze goes down fast, smoothly, in a dense, relatively flat deposit requiring a minimum of finishing. By the elimination of preheating and the elaborate preparation measures necessary for other methods, and

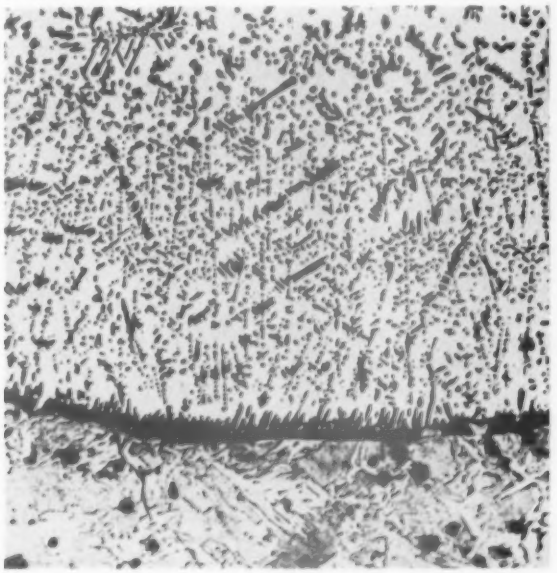

Fig. 16 Photomicrograph of aluminum-bronze deposit on steel plate. $FeCl_3$ etch. × 250

Fig. 17 Aircomatic build-up of steel mill guides

because of the high-speed welding and minimum finishing required, this method can effect impressive economies on many jobs.

Phosphor-tin-bronzes are also used with this method for overlay work—guides, bearings, pads—any job where properties of the alloys can be used to advantage and where the volume of the work justifies its use. Figures 17, 18 and 19 shows the application of phosphor-tin-bronze to mill guides by the Aircomatic process. Not only is the inert-gas-shielded consuming electrode method achieving wide use in the deposition of bronzes but it is used with stainless steel wires for overlay work on valve stems, seats and crane brake wheels.

In general, the production rate of equipment and wires for this method, based on current laboratory tests and commercial applications, will determine the speed with which it finds wider applications. Many details have to be worked out, but the merits of this method are obvious and the demands for its continued development are great. The speed of the inert-gas-shielded arc method with consuming electrode wire, along with its proved ability to transfer all the alloying elements in the wire to the deposit, while controlling base metal dilution to less than five per cent, makes it one of the most significant welding developments in recent years.

CONCLUSION

If the most effective and economical results are to be gained with the hard facing process it is obvious that users must not only select the most effective and economical alloy but apply it in the most effective and economical way. It is the purpose of manufacturers of equipment and materials for hard facing to make this practical objective obtainable.

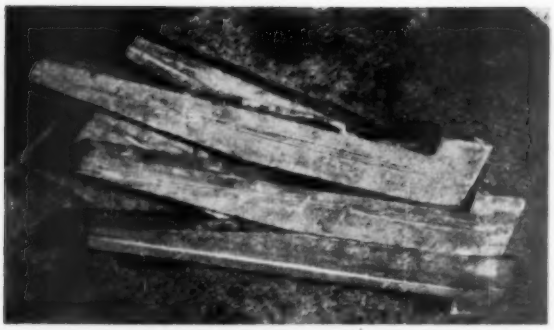

Fig. 18 Mill guides after build-up

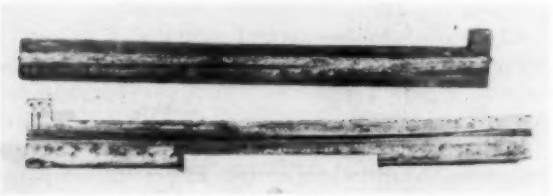

Fig. 19 Steel mill guides of phosphor-tin bronze before and after build-up

The final test of a hard facing deposit lies of course, in the extra service life it gives to the part treated. But the economics of the process extend far beyond this consideration. Where only a small surface of a part must be wear-resistant, hard facing makes it possible to make the basic part of some low-cost material. This principle is behind the every-day production of increasing numbers of composite parts which require small areas of hard facing. Moreover, base metals may be selected which are better suited for the job because of strength requirements. It is not necessary to make a compromise between hardness and strength as would be the case if a tool steel or some form of heat treatment were selected.

Perhaps the really amazing thing about hard facing is this: It is economical even when the cost of a new part is *less* than the cost of the surfacing alloy and the hard facing operation. Why? A restored part with a wear-resistant overlay not only outwears a new part many times over but actually functions more efficiently.

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The Nature of Heat in the Welding Process

Heat flow in welding and other thermal considerations involved in welding procedures

by Robert T. Howard

I. IDEAS ABOUT HEAT AND HOW IT BEHAVES

WHEN we start talking about welding, there are few among us who do not think in terms of a particular process with which we are most accustomed. The most general definition, however, describes welding as the act of joining two or more parts so as to form an integrated whole. This opens to our consideration a number of processes which we most commonly consider separate from welding such as soldering or brazing, or plating and, strangely, even cementing.

The idea of heat in welding comes about from the necessity of heating one or both pieces to be welded up to the liquid or near liquid stage. As liquids the two components mix, or to be more precise, dissolve in each other more readily than they do as solids. As the liquid cools, the solid pieces "grow together." The engineering suitability of the joint thus created is determined by such factors as strength, ductility and soundness, which in their turn are dependent on some basic properties of the kind of base materials, fillers and the environment in which the heating was performed. But here we shall not consider the quality of the weld since it is our purpose only to consider the conditions under which a weld can take place. In this sense then, the usual resistance weld is a fusion weld because the nugget is truly a zone of fusion, although of limited extent. Let us hold ourselves, for the present, to the fusion weld. Later we shall see the how of welding without fusion. But for fusion welding we must think about the characteristics of heat.

If we take a jug of cold molasses and pour it out in as thin a stream as we can on a flat surface, it will pile up until its weight causes it to spread out by flowing out in a circle. By waiting long enough we can see that the molasses will flow out into a very thin but very large circle. The faster we pour, the more it piles up. This is very similar to the way heat behaves. If we take a single point source for heat such as the heliare and hold it steady in the middle of a plate, we known that the heat will pile up and the metal will melt. The faster we put in the heat, the faster it piles up. When we stop the arc and wait, the whole plate eventually gets to be the same temperature, and if the plate is large enough, the temperature gets down essentially to room temperature.

On this piece of polished stainless, Fig. 1, we applied a gas torch just long enough to get a puddle. In flowing away from the melt, the heat raised the temperature enough to oxidize the surface. The amount of oxide formed and therefore the thickness is dependent on the temperature. Optical interference causes the light of only one color to be reflected from a given thickness.

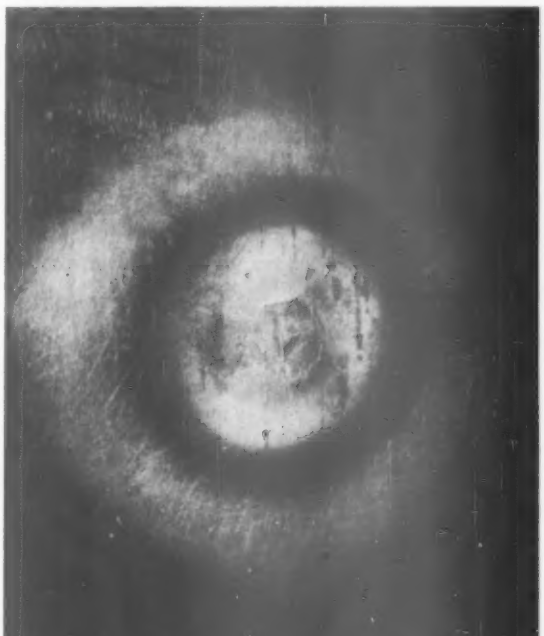

Fig. 1 Isothermal rings in an 18–8 stainless steel plate $\frac{1}{8}$ in. thick heated to fusion at the center with a gas torch

The rings are caused by optical interference colors, which are related to the thickness of the oxide film, which in its turn is proportional to the maximum temperature attained by the metal immediately beneath it.

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Presented as a talk before the Oklahoma City and Dallas Sections of the AMERICAN WELDING SOCIETY.

Therefore, the color is determined by the maximum temperature at that point. Thus we have concentric circles each at the same temperature around the circumference. We have now some idea of how heat behaves, but this raises the question, "What is heat?" This is a question which is not answerable in terms of our senses. We cannot smell it; we cannot taste heat; we cannot hear it; with the sense of feeling we can only infer a different state of heat content by the temperature. We can infer the state of heat by the level of irreducible noise in a telephone circuit. But just as we infer the condition of magnetism by the force on a piece of iron, we infer that the quantity of heat in an object is changing by the change in temperature. We say that the internal energy of a substance is proportional to its temperature above absolute zero.

$$E = TS$$

where S is called the entropy which is a property of the material just as the electrical resistance. (Thus by knowing the entropy we can, by measuring the temperature, gain some idea of the intrinsic heat in the material itself.)

Closely related to the entropy are the heat conductivity and the heat capacity. We know that heat conductivity is very much like electrical conductivity. In metals the two are so closely related that we do not have metals with poor thermal conductivity and good electrical conductivity and vice versa. The quantity of heat that can be carried away from a higher to a lower temperature for a given shape in a definite time is the thermal conductivity. The quantity of heat that can be stored in a given shape for a definite temperature difference is the heat capacity.

These things may seem unnecessarily theoretical but are necessary to understand what happens in melting. There is another concept involved in the transfer of heat in welding. As the solid iron goes to liquid in welding steel, a definite amount of heat is absorbed. In the solid there are a number of transitions requiring heat absorption.

The total heat absorbed per unit time per unit weight then will be:

Amount of heat to raise steel to melting point.
Amount of heat absorbed in transitions.
Amount of heat lost by conduction.
Amount of heat lost by other reasons.

The heat input is equal in manual arc welding to the current times the voltage/1000 (for Btu/sec) plus the heat from burning the coating. At 150 amp and 35 v this is enough heat to melt 0.02 lb of steel per second. Of course only three-fourths of this heat reaches the metal because of radiation and other causes, but we now begin to see the importance of such factors as thickness, conductivity and travel.

As the source of heat (i.e., the arc in arc welding) moves along, the circles shown in the previous plate become elongated into ellipses, longer and narrower, the greater the rate of travel. In Fig. 2, taken from

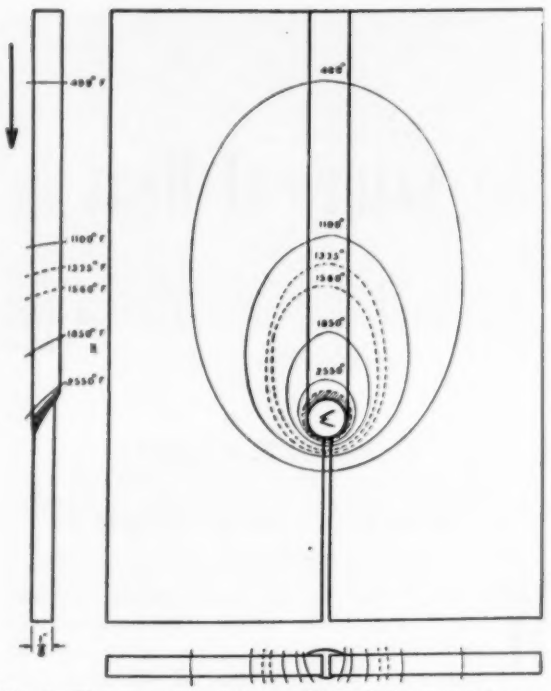

Fig. 2 The temperature in a mild steel plate at an instant during welding

W, liquid weld metal (weld melt), the shaded area is the metal that is in the mush stage, the boundaries of which are the liquidus and solidus temperatures—2768 and 2714° F, respectively. Between the shaded area and the curve labeled 1560 and 1335° F is a mixture of ferrite and austenite. Arrow indicates direction of welding.

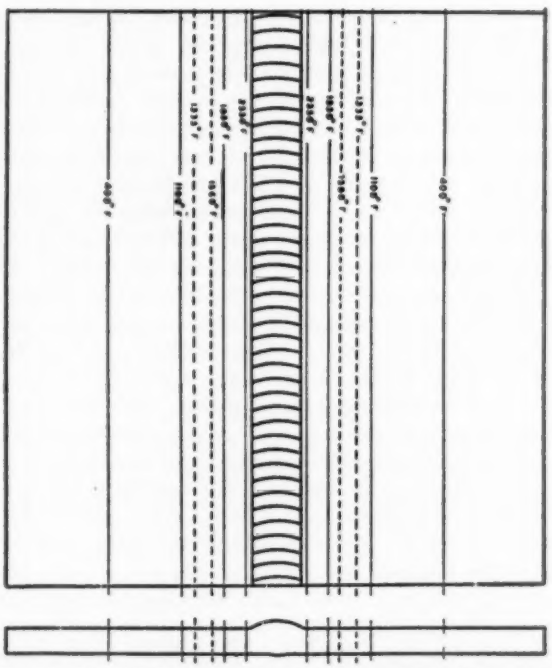

Fig. 3 Distribution of maximum temperatures in welding a steel plate

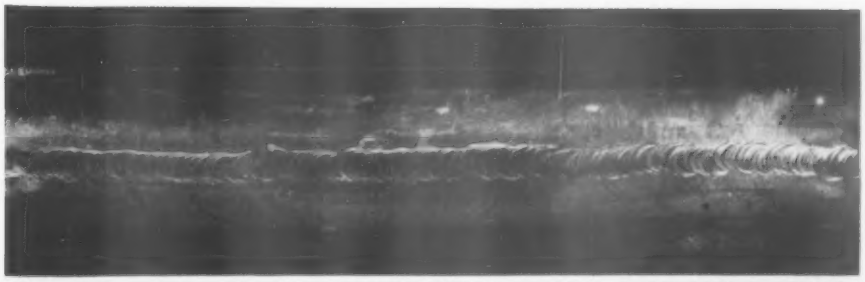

Fig. 4 18–8 stainless steel plate 1/8 in. thick fused by Heliarc at 10 ipm, using nominal heat

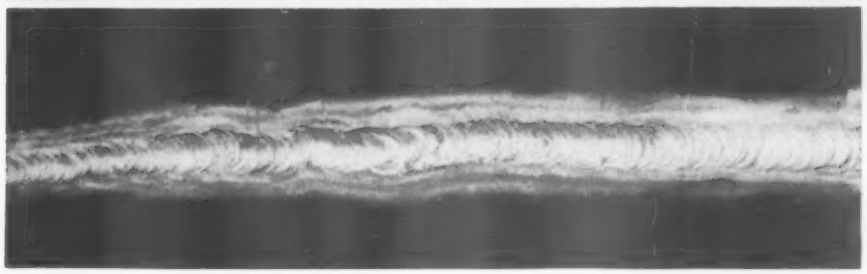

Fig. 5 18–8 stainless steel plate 1/8 in. thick fused at 20 ipm using nominal heat

Welding Metallurgy by Henry and Claussen, we see the idea shown schematically for a steel plate upon which measurements were actually made. Here, the maximum temperature, as far as we are concerned metallurgically, is the equilibrium temperature between the liquid puddle and the solid plate. The lines shown here at equal temperature are called "isotherms" meaning constant temperature lines. As the ellipses pass a fixed point near the bead, it will be easily seen that the plate then exhibits zones of maximum temperature parallel to the motion of the arc. This is revealed in Fig. 3 for the same plate.

The greater the heat input, the slower the travel, the higher the temperature of the base plate, the greater the conductivity of the base plate, the stiller the air, the wider will be the distance between two parallel lines of equal temperature either side of the weld or bead.

Figures 4 and 5 show very clearly the difference in width of the heat-affected zone caused by different rates of travel in a stainless steel plate as revealed by the interference colors.

II. THE ROLE OF HEAT IN THE METALLURGICAL VARIABLES

At this point it becomes important to list the metallurgically important variables having a relation to the effects of amount of heat, temperature and rate of change of heat and/or temperature. The following table sets forth these factors, as they occur in heating and cooling. From the viewpoint of practical arc welding, results are the guiding thing; therefore, the most important undesirables are these, controllable from the heat viewpoint, but not necessarily in order of importance:

1. Thermal cracks.
2. Distortion.
3. Locked up stresses.
4. Gas porosity.
5. Excessive grain growth.
6. Hardening cracks.

	Heating	*Cooling*
Temperature	Thermal expansion	Thermal contraction
	Recrystallization (stress relief)	Thermal conduction
	Loss of strength	Gain of strength
	Crystal transformations	Crystal transformations
	Melting	Freezing
	Vaporization	Condensation
	Radiation	Evolution of gas
Rate of change of temperature or amount of heat	Grain growth	Hardening
	Crystal transformations	Crystal transformations
		Thermal cracks
		Hydrogen embrittlement
Amount of heat	Size of bead	Distortion
	Amount of recrystallization	
	Amount of crystal transformations	Crystal transformations
	Amount of base plate melted	Freezing time

Because the factors in the left-hand column are interdependent, their effects in dealing with these troubles must be considered together. Rates of heating or cooling are governed by maximum temperatures and differences of temperature. For this reason troubles due to rates of heat transfer will be discussed following the ones caused by thermal gradients. Those which are controlled by temperature, temperature gradients or differences, and the relative amounts of heat energy can be minimized by the following steps.

1. Reduce the unit heat input. Since the minimum temperature for fusion welding is the melting point of the metal, it is obvious that fusing more than the amount of metal needed to join the pieces increases the heat requirement. Therefore, reduce the size of bead or nugget to the minimum consistent with good design.

2. Increase the rate of heat input. Since the rate of heat loss is controlled by the thermal conductivity, and since the melting point temperature is that at the interface of the liquid and solid metal, for a given thickness it would be desirable to complete the weld and move away before any heat has been transferred to the base metal. This is because if the thermal contraction of freezing is balanced by the thermal expansion of the heat-affected zone, less dimensional change would result by postponement of freezing until after the deposit is made, thus less residual stresses would ensue. This, of course, is impossible. But we can raise the heat and speed and increase the size of the manual rod to transfer a maximum amount of liquid metal from electrode to base metal per unit time, since all metal transferred is liquid. In the case of automatic feed of filler wire, the rate of feed can be stepped up while reducing the wire size. By this practice it is possible to concentrate the source of energy and raise the unit rate of input. Also advantages result since exceedingly high energy densities can be tolerated at wire speeds so large as to exceed the rate of thermal conduction back along the wire. Here electrical contact is made near the point of deposit so as to reduce resistive heating even at several thousand amperes. It is necessary only to bear in mind certain other conditions which must be met such as allowing enough time for fusing the base metal, evolution of gas before freezing, etc. These factors set the maximum speed of welding for a given heat input.

3. Increase the extraction of heat after freezing. This can be done by quenching or blowing with helium or dry ice backups as in the case of stainless steel.

Heat control in handling gas porosity, hardening cracks and hydrogen embrittlement all depend on reducing the cooling rate in three separate temperature ranges. By reducing the freezing rate, gas evolved in cooling of the liquid has a chance to bubble out without entrapment. Hardening in steel with a carbon equivalent higher than 0.50% can be controlled by reducing cooling rates in the vicinity of 1000° F. Hydrogen embrittlement in steel is the result of too rapid cooling at less than 400° F. All of these situations may be corrected when they are problems by more or less preheat, slower travel, more passes with smaller electrodes, etc. Since preheating is costly, resort to such other solutions as the use of low hydrogen electrodes in the last case may be the more desirable for high production.

The arc welding of stainless steel illustrates the application of these principles. The thermal conductivity of stainless is one-fourth that of carbon steel while the thermal expansion is 1.5 times that of carbon steel, therefore, a crude sort of distortion factor, which is a relating cause of thermal cracks, is about 6 times that of carbon steel. Here, especially when welding upon thin stainless, it is desirable to use large manual electrode at high heat and fast travel with dry ice or air blast backup to minimize distortion and cracking. With aluminum the conductivity is 3 times that of carbon steel and the thermal expansion twice, making a distortion factor of two-thirds that of carbon steel. The problem is to supply enough heat to the base metal to allow joining to take place. Cracking may occur here because of the relatively high temperatures and thermal expansion (coupled with low strength) adjacent to the weld where the rate of heat input just exceeds the conductive loss. The solution again lies in stepping up the rate of heat input, although postfreezing measures necessary for stainless steel may even be reversed to the extent of need for postheating.

In these discussions, no attempt has been made to present an all embracing cure for the problems which beset the welding foremen or methods engineers. Rather, I have tried to present the general causes and the effects of variables which may come in different combinations. The solution to a particular problem, which perhaps is unique in its time, place and kind results from the intelligent application and combinations of some fundamental ideas and principles which I have attempted to present here.

Fortunately, the practices discussed here, with the exception of preheating and postheating, not only are good technically but excellent costwise. These methods have been presented for your consideration because they have been tried and tested in cost-conscious shops. As most frequently happens, gentlemen, the best methods technically and quality-wise are best for high production at the least cost.

III. HEAT AND THE ATOMIC MODEL

A thorough discussion of the submicroscopic picture of heat cannot be attempted intelligently here, except allegorically. It is possible to visualize, however, a three-dimensional lattice work of elastic balls held together by springs under compression and bounded by a surface lattice of balls bound by very strong springs in tension. Such a regularly arranged conglomeration of spherical bodies would have a certain amount of bound—in energy even at rest or, if we liken it to substance, at absolute zero. If we set the balls vibrating as with an alternating magnetic field located near one of the faces, the motion would spread throughout the lattice. In like fashion is the spread of heat throughout a metal. Here the frequency of oscillation of the spheres is comparable to the effects of atomic motion at different temperatures.

The partial disintegration or partial breaking of the spring bonds simulates melting, in which there are still strong atomic bonds, yet those which held the crystal in a compact erect mass have disappeared leaving the substance shapeless except in a container, suitable to the liquid.

As the bonds break completely under intense oscillations, the spheres are ejected into space as occurs with respect to atoms during vaporization.

Returning to the solid spring model, the inclusion of a definite percentage of larger balls in the lattice

would overcompress and stiffen the mass, as is analogous to afloying.

We have said nothing concerning the nature of the "hooks" or "glue" by which the balls are attached to the springs because scientifically very little is known about the nature of the bonds between metallic atoms. We can say they are very strong and that they show no preference among atoms of the same kind. They exist in definite directions and will accommodate other atoms of the same general kind. Thus, when entire planes of atoms slide past each other in plastic flow, these bonds become temporarily "unglued"; but when the cold working ceases the bonds are remade—atom to atom and plane to plane—as strong or stronger than before.

This "homing" tendency of the bonding forces opens up interesting explanations for well-known facts. For instance, although the roughness of AA gage blocks is immense on the submicroscopic scale, still relatively large areas of atoms come into intimate contact, one with the other, when gage blocks are "wrung" together. Some idea of the immensity of the interatomic bonding forces is gained if we realize that perhaps only a few per cent of the surface areas are actually in atomic contact. Yet the force necessary to separate gage blocks in a direction perpendicular to the surfaces is very large.

Therefore, if we can continue to place the atoms of two pieces of metal, to be welded together in as intimate contact as in a normal solid metal, the atomic bonding affinities should allow completion of the weld without fusion or diffusion. Great advantages should be realized in the welding of dissimilar metals allowing the elimination of brittle intermetallic compounds, undesirable absorption of gasses and other evils besetting the welding engineer. By the application of great pressures causing the upsetting of supercleaned interfaces, many dissimilar metals can be "cold welded." The tendency of the dissimilar atoms to form bonds with each other, the intimacy of contact and the surface cleanliness are the limiting factors in producing welds without fusion. "Pressure welding" or "cold welding" is becoming highly important in the technology of dissimilar materials.

The concept of very short range but immense forces applies to the progressive freezing of molten metal. The atoms slow their oscillations in the shapeless, partially coherent puddle. This means that heat is flowing out through the boundaries of the puddle. Thus the atoms at these boundaries are the first to attain the energetic states of solid atoms. If this happens when the atoms are within range of these immense bonding forces the atoms assume their places in the advancing lattice. This process is repeated over and over as growth of the solid phase proceeds.

It is interesting to note here that electroplating consists (in the most elemental concept) in the reduction of metal atoms from their oxidized valence states to the metallic condition within the reach of these atomic forces. Thus building a metallic coating in electroplating requires the exercise of the same kind of scientific knowledge as consideration of liquid metal freezing in the bead or nugget.

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(*Continued on page 147*)

PRACTICAL WELDER AND DESIGNER

Hand-Cutting Clinic

by P. F. McGonagle

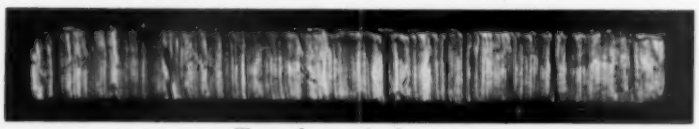
IF THESE THINGS HAPPEN WHEN YOU CUT . . . . . HERE IS THE REMEDY

Gouging at bottom.

Make preheat flames longer—should be about 1/4 in. long.

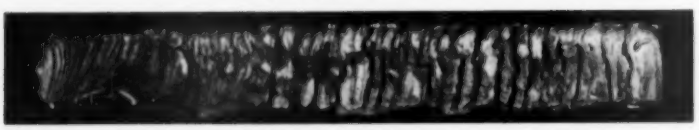
Cut irregular, too much slag, top surface melted over.

Preheat flames are too long—should be about 1/4 in. long.



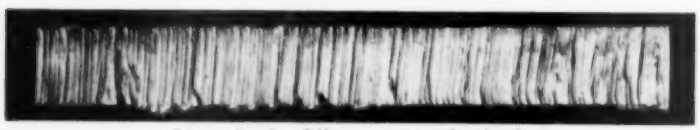
Top edge melted over.

Increase oxygen pressure—check your pressure chart.



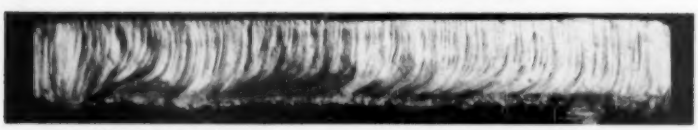
No control of the cut.

Cut down oxygen pressure—check your chart for correct pressure and nozzle size.



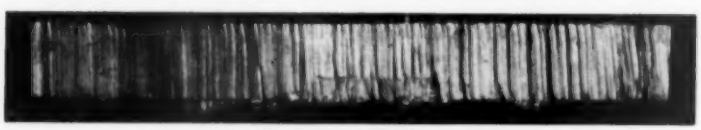
Irregular kerf lines are emphasized.

Increase cutting speed.



Cut edge is irregular—rake to the lag or kerf lines.

Decrease cutting speed.

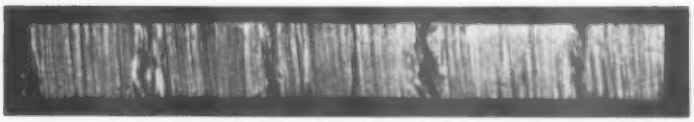


Cut edge wavy and irregular.

Use left hand as pivot—right hand guides the blowpipe. Movements must be smooth and steady.

P. F. McGonagle is connected with the Linde Air Products Co., Cleveland, Ohio

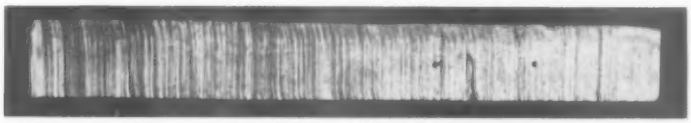
IF THESE THINGS HAPPEN WHEN YOU CUT . . . . . HERE IS THE REMEDY



Gouges where cut was lost and restarted.

Preheat—and press down cutting-oxygen lever slowly just as when starting cut.

MAKE YOUR CUTS LOOK LIKE THIS



This is a good cut in 1-in. plate. The edge is square, and the drag lines are vertical and not too pronounced.

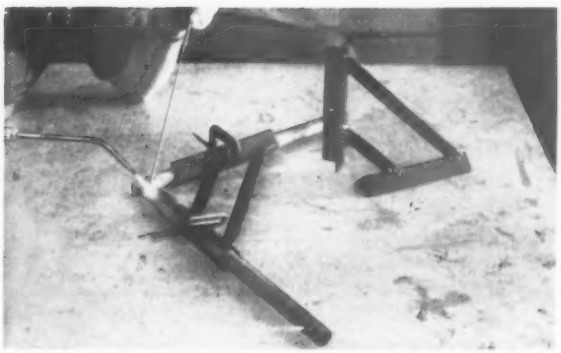


***Fig. 1** All sizes and shapes of pipe or bar stock can be welded on this right-angle jig. C-clamps hold the stock in the jig during welding*

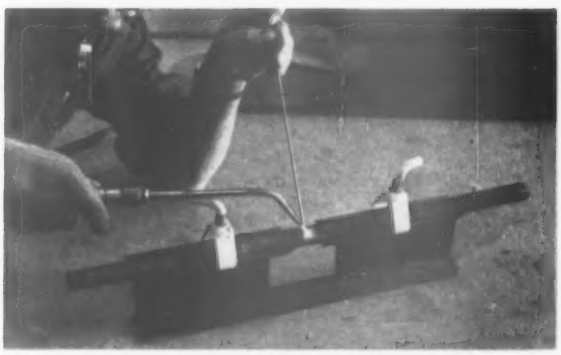


***Fig. 2** Build-in clamps hold stock being welded in this straight jig. This design is suitable for larger jigs to be used when welding large diameter stock*

Two Jigs for Welding Pipe

by H. J. Adolf

IT IS an easy job to weld pipe or bar stock at right angles or in a straight line if you have jigs which correctly position the pieces to be welded. Here are two jigs designed and built from scrap metal. You can make similar jigs with your oxy-acetylene blowpipe.

Angle iron and flat iron struts are the only material needed to make this right-angle aligning and holding jig. Choose the size and length of angle iron best suited to your needs. Clamp these angle iron pieces to the inside edges of a carpenter's square. Now the struts must be welded in place to hold the angle iron. Before welding, cut both ends of each strut at a 45-deg angle. Braze weld the struts between the angle iron parts.

If the heat of welding has caused jig to become warped and out of line, hammer the longer strut until it bends slightly and returns the jig to its proper shape.

Angle iron and flat iron strut also form the main parts of the pipe-welding jig. For the clamps on this jig, you need two $^1/_2$- or $^5/_8$-in. nuts, two bolts to fit, and some narrow strap iron about one inch in width.

Braze weld pieces of flat iron to the angle iron base. Shorter lengths of angle iron are then welded on top of the struts to form the pipe or bar rests. The clamps are made by welding a nut to a piece of strap iron which has been bent to shape and welded to the stock rests. Cut the heads from the bolts, bend the bolt shanks to an "L" shape and thread them onto the nuts. The open gap left in the center permits welding to be done all around the pipe.

Both of these jigs can be used for pipe, tube and bar stock of all shapes.

H. J. Adolf, 2016 Gaynor Ave. Richmond 5, Calif.

Potential Hazard from Use of Thoriated Tungsten Electrodes

Investigation shows the extent to which thoriated tungsten electrodes can be used without significant hazard

THORIATED tungsten electrodes have gained widespread acceptance since their introduction several years ago because of several advantages which they possess over pure tungsten electrodes. The advantages, which are generally accepted, are greater freedom from weld metal contamination, easier arc starting, greater arc stability and high current-carrying capacity. Both ease of operation and economy are factors which contribute to their popularity.

Within the group of industries which manufacture, market and utilize welding equipment, a serious question has arisen recently about the alleged hazard associated with the use of thoriated tungsten electrodes for inert-gas-shielded arc welding. The basis on which rests the suspicion that a hazard may exist is that thorium oxide, an ingredient of the electrode, possesses natural radioactivity.

Several months ago, the Health and Safety Division of the New York Office, Atomic Energy Commission, was consulted by one of the NYO contractors regarding the potential hazard in the use of thoriated tungsten. This contractor was contemplating an extensive use of inert arc welding and requested recommendations of appropriate precautions. Since the Health and Safety Division did not have nor could find specific information on the subject, an investigation was launched. This investigation was made possible through the cooperation of a local manufacturer of welding equipment that made available laboratory facilities. The general scope of the project was to determine whether the use of thoriated tungsten electrodes created a hazard due to radioactivity and, if so, to formulate recommendations for suitable protective measures.

The conclusions derived from this experimental work are as follows:

1. When thoriated tungsten electrodes are used to generate an arc, radioactive thoria is released from the arc and becomes airborne as a fume. The rate of release is a direct function of the rate of electrode consumption, which in turn depends on such factors as current flow, electrode diameter and welding technique.

2. The activity released may be sufficient to exceed the recommended maximum allowable concentration [70 alpha disintegrations per minute per cubic meter of air ($ad/m/M^3$)] at a distance of 6 in. from the arc. All general air samples, collected 12 in. from the arc or beyond, were well below this maximum permissible concentration; most samples measured only 10 $ad/m/M^3$ or less.

3. The activity which is released in the fume is sufficiently diluted by normal convection currents that the concentration at the breathing zone of the operator is well below the maximum allowable. No detectable activity was found in any of the breathing zone samples.

4. The tests which were covered included a variety of commercial welding techniques. In general, high current densities were employed to simulate the most adverse conditions of fume dispersion. None of these techniques produced sufficient radioactivity in the breathing zone of the operator to be considered a hazard.

5. It cannot be stated conclusively that under no circumstances would the maximum permissible concentration be exceeded. It is conceivable that the use of this equipment in a small totally enclosed space might result in excessive concentrations.

6. External radiation from the handling of these rods in any practical quantity is insignificant.

7. It may be concluded that, within the limits of the test which has been conducted, inert gas welding using thoriated tungsten electrodes may be employed with no significant hazard to the operator or to other room occupants. Special ventilation or protective equipment is not indicated for the protection from radioactive fumes.

Copies of the complete report covering this investigation may be obtained by writing to U. S. Atomic Energy Commission, New York Operations Office, P. O. Box 30, Ansonia Station, New York 23, N. Y.; attention A. J. Breslin.

Abstracted from the report "Investigation of the Potential Hazard from the Use of Thoriated Tungsten Electrodes in Inert-Gas-Shielded Arc Welding," by A. J. Breslin and W. B. Harris, originally published in the December 1952 issue of the *American Industrial Hygiene Association Quarterly*.

Case Reports on Welded Structures

Typical welded structures recently completed in various parts of the country. Included also are details of different welded connections as suggestions for designing similar structures. Courtesy, Lincoln Electric Co.

13-Story Welded Framework Saves 25% Steel

by Ned H. Abrams

EFFICIENT use of all-welded prefabricated construction has cut steel needs by 25% and costs by 20% on this 900-ton framework. Total weight of the hotel building is estimated at one-third less than conventional structures making this 13-story, 100- x 155-ft building one of the lightest, yet strongest, structures in the Pacific Northwest.

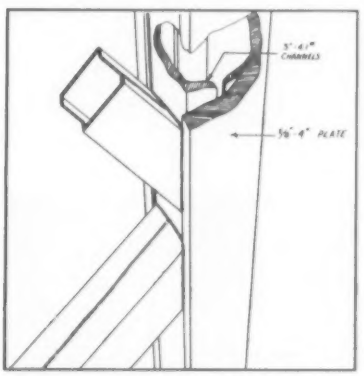


Fig. 1 Typical detail. Lattice column shop fabricated at low cost from 3-in., 4.1-lb channels and ⅝-in. plates

Ned H. Abrams is an architect in Sunnyvale, Calif.

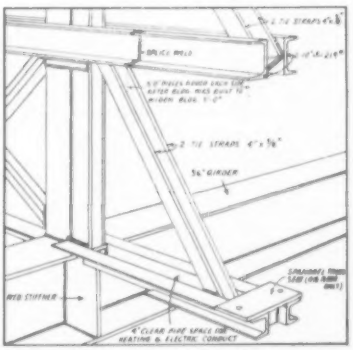
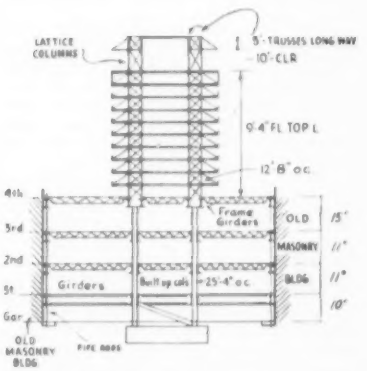


Fig. 2 Column and spandrel support. Typical detail, 4th to 11th stories. Shows addition of 5 ft to building by splicing 10-in. channels to the frame. Tie straps are 4- x ⅜-in. angles

Light, open trusses carry most of the dead loads to the columns. Structural members are shop fabricated at low cost with fast, downhand welding techniques. Lattice columns are erected from the street while other framework is erected from a crane platform on the fourth floor level using a 123-ft boom.

During construction it was decided to increase the width of the framework from 40 to 45 ft. Had it not been for the welded design, such a modification would have entailed considerable cost.



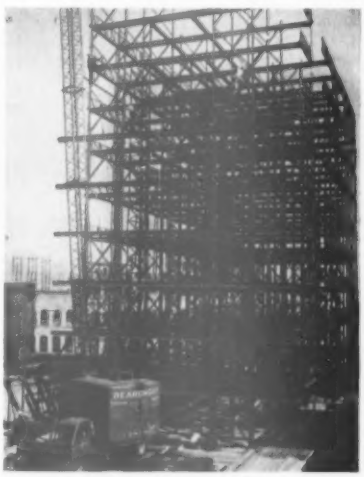


Fig. 3 All-welded framework for the 13-story Ridpath Hotel, Spokane, Wash. Steel fabricators: Union Iron Works. Erectors: Dix Steel Co., Spokane, Wash.

Welded Frame Design Cuts Steel Tonnage 15% on Department Store

THROUGH welded structural design, it has been possible to save 15% on steel in the framework for J. W. Robinson's new department store in Los Angeles. One of the most recent department store in Southern California, this 1700-ton frame is almost entirely field welded.

The relationship of the columns and girders provides both vertical and horizontal continuity with a minimum of welding. The horizontal continuity reduces the deflection of the 32-ft beam and girder spans to approximately 25% of what it would have been if they had been simply supported.

All girders are continuous through the column lines—the column rather

Fig. 4 Typical column joint. Develops continuity both vertically and horizontally. Vertical column continuities are shop welded to the continuous beam. Top plate, with slot to give extra weld area, develops continuity in transverse beams across column supports

Fig. 5 Detail of girder running through column. Column top and base are welded to beam flange. Vertical stiffeners provide continuity to column

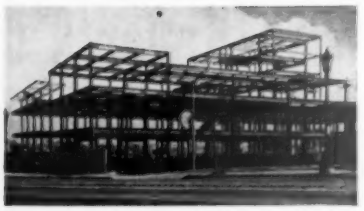


Fig. 6 Four-story rigid frame for the J. W. Robinson Department Store in Los Angeles, Calif. Architects: Perreira and Luckman and Charles O. Matcham. Structural designing and detailing: Paul E. Jeffers and Robert Wilder, associate structural engineers. Steel fabricators: Bethlehem Pacific Coast Steel Corp.

Fig. 7 Continuous girder passing over column top is spliced at point of minimum stress

than the girder being spliced at that point—and extend to a point approximately 6.5 ft from the columns on both ends. This leaves a space in alternate spans of approximately 19 ft. between girder ends in which a suspended span is carried.

This design idea also allows any variations in gap to be compensated in the splice welds and so further simplify field welding.

Approximately 6 in. less height per story results from this welded frame design. Distances between ceiling of one floor and the floor level above are also considerably less than with other types of construction.

Welded Design Speeds Erection. . .Cuts Construction Costs 23% on Factory Building

by W. A. Repp

A FASTER, simpler method for constructing buildings with welded steel has gained several important benefits for our clients. For example, on this 500-ton framework, welded design enabled three 5-man crews to set and weld all steel in only 70 days. The structural cost for fabricating and erecting came to only $150 per ton as compared to $195 for traditional methods.

After construction was under way the owner decided to add a second story because of an increase in business. To accommodate his request required only to increase the column and beam sizes for the first floor and transfer original columns and beams

W. A. Repp is connected with Repp & Mundt, Inc., Contractors, Columbus, Ind.

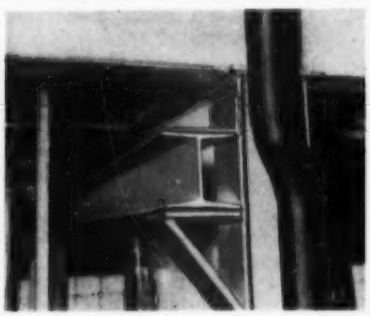


Fig. 8 Typical beam-to-column connection designed for second-floor loading of 200 psf. Columns are 8 × 8 in. and beams 12- x 12-in. H beams. Also shows bracket for crane rail

Fig. 9 Column-to-base detail. Joint is welded in position after column is erected and plumbed

Fig. 10 120,000-sq ft factory building for the Hamilton Manufacturing Co., Columbus, Ind. Factor will eventually enclose all the area to the boiler house

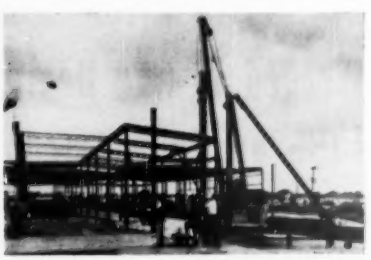


Fig. 11 Erecting columns using 1½-ton stiff leg derrick

to the second floor. With this design neither the owner nor the contractor was penalized through increased costs or delays in construction time.

Using simple, stiff-leg derricks, columns were positioned on embedded base plates. When a number of columns were erected, beams were hoisted in position and welded. Structural members, like brackets and braces, were flame cut on the job and welded as required.

Welded Design Cuts Steel to 8.5 Lb/Sq Ft on Airport Hangar

by J. R. Pelich

THE welded steel framework for this new hangar weighs but 8.5 lb per square foot of roof area. The roof dead load is only 20 psf as a result of advantages gained by the two-hinged parabolic all-welded truss-arch design.

J. R. Pelich is an architect in Forth Worth, Tex.

Each arch weighs 13.5 tons and is fabricated in four sections for ease of handling. Supported on A-frames, and spaced 20 ft apart, the trussed arches span 257 ft. Designed for fast, easy fabricating, they require only three field splices. The 9 arches, purlins and bracing were set in only 12 days with an average crew of 8 men. Erection required only one steel scaffolding tower and a 100-ft steel gin pole.

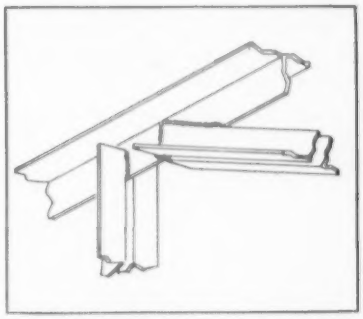


Fig. 13 Typical joint detail shows simplicity of construction with welded design. Top truss member is 6-in., WF, 26.5-lb tee with 8- x $^1/_2$-in. plate plug welded every 6 in.

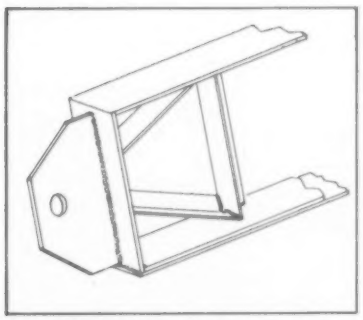


Fig. 12 Typical pin detail on one of nine parabolic welded trussed arches. Arches have a constant depth (3 ft) back-to-back of tees and rise of 48 ft 8 in.

Fig. 14 Terminal Building Annex for the greater Fort Worth International Airport, Fort Worth, Tex. Jos. R. Pelich and P. M. Geren, associated architects; Thomas S. Bryne, Inc., engineers and general contractors; North Texas Steel Co., Inc., fabricators; John F. Beasley Construction Co., erectors

Welded Design Saves 48 Tons of Steel. . .Cuts Erection Time and Cost on YMCA Building

by Emerson C. Scholer

THE use of welded design has made it possible to cut our steel requirements by 15% on the new YMCA building in Tucson, Ariz. Several weeks saved in the fabrication and

Emerson C. Scholer is connected with Scholer, Sakellar & Fuller, Architects, Tucson, Ariz.

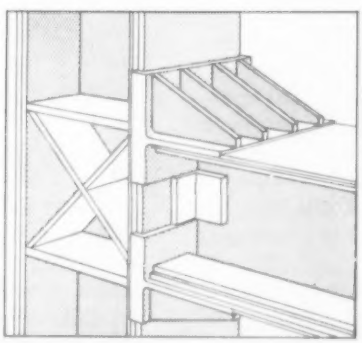


Fig. 15 Simple beam-to-column connection for 325-ton rigid framework, new YMCA building, Tucson, Ariz.

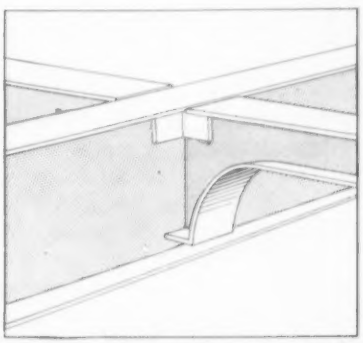


Fig. 16 Typical, low-cost detail for cross bracing. Permits fast, simple field welding. Sketches show element of construction without welds

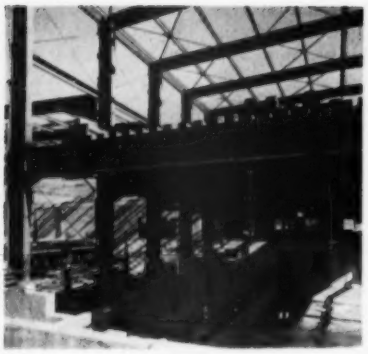


Fig. 17 Section of framework over swimming pool. Shows clean, simple design

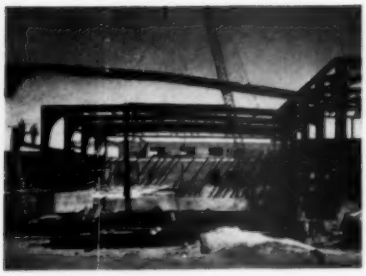


Fig. 18 Lowering rigid beam into place. Beam is 24-in., WF, 76-lb I-section tapered, with radius of 7 ft 6 in. at haunches. Beam rests on seat clips for field welding to columns

erection of the 325-ton steel framework have, in addition, netted substantial reductions in overall costs.

The rigid bent construction used on this project provides a 77-ft clear span for the gymnasium and a 62-ft span for the swimming pool. The overhead clearance, achieved with welded design, provides a clear, unobstructed view from all parts of the enclosure. Simple in design, the beams and columns are easily fabricated in any steel shop and can be erected with a construction crew of 6 men.

Fabricators and erectors: Chapman Dyer Steel Manufacturing Co. General contractor: H. L. McCoy Construction Co.

Welded Designs Cut Structural Costs 50% on Fairground Buildings

by David R. Graham

STRUCTURAL designs that utilize the economies of welded frames and continuous connections enable the engineer to effect savings up to 50% in structural cost while cutting steel tonnage by 25%.

The recent construction of the live stock building for the Tulsa Fair Grounds was completed at a total cost of $112,000 or $1.12 per square foot. If this same building were to have been designed for any other than welded construction, its cost would have been $2 per square foot. Bolted or riveted construction would have required from 5 to 6 lb of structural steel per square foot. The welded design required only 3½ lb per square foot.

In an exhibition building of this kind, rigid frames, of course, provide the unrestricted vision so essential in addition to the extreme economy and simplicity of erection.

David R. Graham is a Consulting Engineer in Tulsa, Okla.

Fig. 19 One of 12 bays, 32 ft x 200 ft, that provide tie spaces for 1100 cattle. Roof is corrugated iron and includes 1080 plastic skylights

Plymetal Seen Preferred for Carbide Tool Brazing

USE of plymetal shims for brazing carbide tool tips has become the generally accepted method adopted by U. S. metal manufacturers, replacing the "sandwich" brazing technique, according to Ross Bayes, executive vice-president of The American Platinum Works.

The preferred position of plymetal in this field has been gained in the relatively short time of two years, Mr. Bayes said.

Explaining Silvaloy's rapid acceptance, he pointed out that the two chief advantages to manufacturers are economy and efficiency. Drastic reductions in brazing costs and increased production rates have been reported in plants throughout the country, with some firms noting a doubling of productive volume.

Principal labor-saving factor involved is the use of one plymetal shim instead of the three formerly required to braze carbide-cutting tools tips. Heat is applied to the units following the simple procedure of fluxing and positioning, thus placing minimum emphasis on skilled workmanship. In addition, Mr. Bayes said, the need for sandblasting and rubber wheel clean-up is almost completely eliminated.

Because plymetal eliminates excessive thermal or other stress in the brazed joint, it is being used successfully in other applications where brazed areas must be free of stress, in addition to carbide tool tips, Mr. Bayes stated.

Production Welding with Inert Metal Arc at 100 IPM

THE J. S. Thorn Co., of Philadelphia, pioneers in the fabrication of aluminum window frames and sash, is using the Aircomatic head to weld 15-ft seams in $^{3}/_{16}$-in. thick 61S-T6 aluminum at 100 ipm. The $^{3}/_{32}$-in. diam 43S filler wire is supplied from a mechanical wire-feed unit. No flux is required because of the protection afforded by the helium shielding gas employed. No special preparations are necessary. The head is run on standard track that is accurately aligned with the seam. The operator has only to start and stop the equipment at the beginning and end of each seam.

The finished Deck Balks, completely water tight after welding in end sections with a manual Aircomatic Gun, successfully pass both hydrostatic and load tests.

Superweapon

PRODUCTION techniques that resulted in completion of an "assembly-line" model of Army Ordnance's newest superweapon—an artillery piece capable of firing an atomic missile—exemplify America's industrial capabilities.

Prototype of the new gun was made piece by piece at Watertown Arsenal, Watertown, Mass. During its construction, engineers worked to solve the problems of stresses, weights and a myriad of other factors.

Although Dravo Corp. received its first order for an undisclosed number of the gun carriages by letter from the Pittsburgh Ordinance District in February 1951, some 2200 necessary drawings were not completed and ready for use until mid-summer.

In late November, fitting and welding jigs, dies and gages had been completed and fabrication of steel plate was started in Dravo's Structural and Sheet Metal Shops. On July 18th, the first carriage left Pittsburgh by rail.

Large weldment in the assembly is the top carriage 38$^{1}/_{2}$ ft long. It is made up of two double-web girders joined by transverse steel frames. Stainless steel flanges are fixed to the bottom of the girders. Steel castings are welded inside for bearings and gears.

To assemble the top carriage it was necessary first to fabricate subassemblies of component parts. Tolerances allowed for the subassemblies of the top carriage were only $^{1}/_{32}$ of an inch because parts had to fit closely.

The side girders of the carriage were built in special jigs. Transverse members were installed to join them. In the final welding stages of this assembly, the carriage is rotated 11 different times to permit welding according to a procedure designed to lessen distortion. All steel castings in the top carriage were preheated before being welded. After welding, the top carriage was sandblasted, given an acid bath and painted.

First machine operation on the carriage was the stainless steel slides. A special fixture was designed and built to support the carriage on a 26-ft planing machine. One-half the slides were machined at a time; then the fixture with the carriage on it was

U. S. Army Photo

Fig. 1 The 280-Mm. "A" Gun

The U. S. Army's newest weapon, a generator-powered gun transported by specially designed trucks at the Aberdeen Proving Grounds, moves along the street.

rotated and the other half completed. A large boring mill cut the holes in the carriage for gear shafts and other parts.

The cradle tube assembly which is supported on the carriage with trunnions is a heavy alloy steel casting, with stiffeners and trunnions of the same material. It had to be preheated to and maintained at 700° F for welding operations. Critical operation on the cradle was alignment of the two trunnions with a keyway that receives the gun barrel's key. The keyway is 3 in. wide and 8 ft long. To cut this slot within the tube, a fixture was developed to support the entire assembly on a planing machine. Using sets of progressively wider cutting tools, attached to a bar connected to the planer head, the keyway was cut.

Another special fixture had to be used for machining a rack slide which is located on the rear of the carriage to guide its movement sideways. To cut on the specified radius, a steel segment was supported on a pedestal bolted to the floor several feet away from the planing machine. The other end of the segment was attached to the planer table. Movement of the planer table drew the piece along the stationary cutting head and provided the necessary arc.

Weight of the gun carriage is a vital factor due to the necessity of transporting the weapon over bridges, culverts and terrain which might not be sufficiently strong or stable to support it. At the same time, the carriage and its equipment has to be fabricated to resist the force of discharge recoil and stresses of being transported. Ordnance designers specified the use of

Fig. 2 Retraction stop pads on the carriage, being machined with a 26-ft planer

many types of hightensile, carbon, alloy and stainless steels, plus lightweight aluminum and magnesium, and bronze and brass for the structural parts, castings, forgings and fittings. Wherever a pound could be saved without sacrificing strength, it was done.

Welding plays a major role in fabricating the carriage. To assure stronger, smoother welds, most of it is done in the downhand position. A total of approximately 8200 ft of welding is required in building one assembly and its component parts. Every weld is inspected, before and after the pieces are stress relieved, with a Magnaflux machine or by the dye penetration process.

Development of the special jigs and fixtures enabled faster production of the carriage on an assembly-line basis and assured that the work would be completed within the critical specifications and tolerances. These production aids also permitted the use of available machine tools without delaying manufacturing for several months to build special equipment.

Close liaison is maintained constantly with personnel or Watertown Arsenal and the Pittsburgh Ordnance District in problems of material procurement, specifications, and all other phases of the project. Resident Ordnance Inspectors at the Dravo plant provide technical assistance and cooperate in the painstaking, intricate work.

Fig. 3 The cradle (for the barrel) being assembled to the carriage

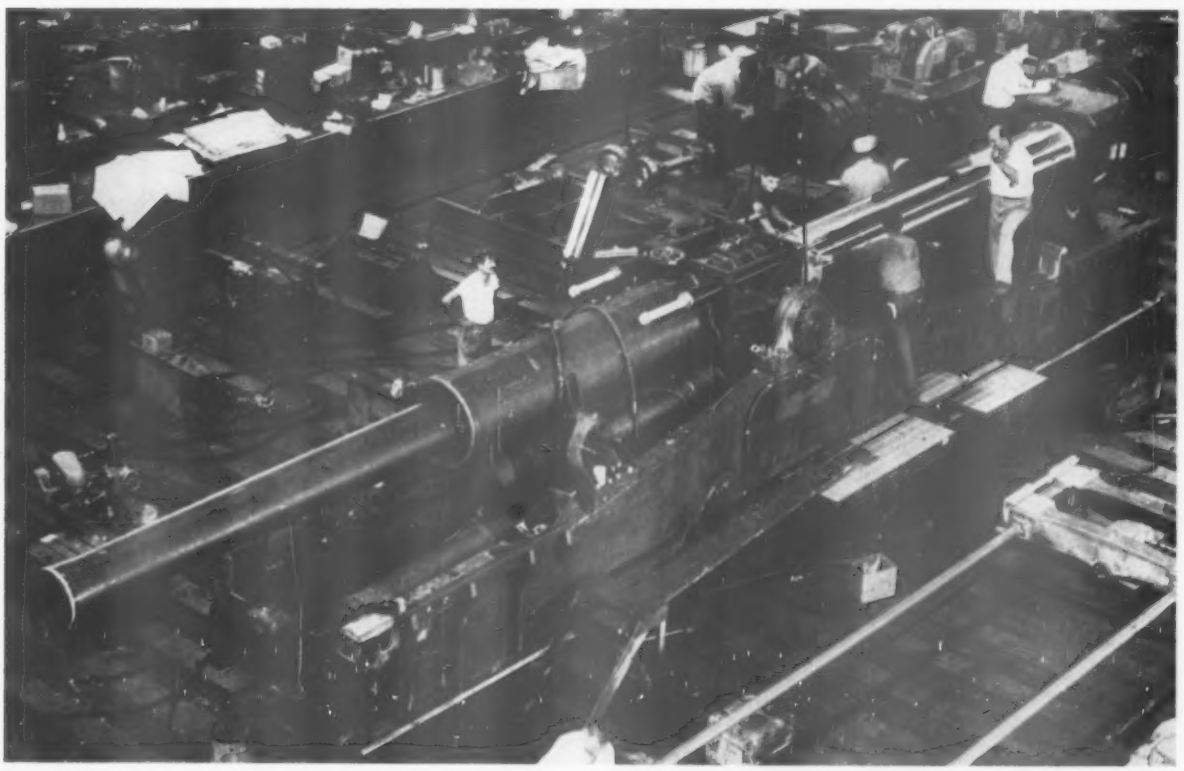


Fig. 4 Production Model of Carriage for Army's new 280-Mm Gun which can fire an atomic shell

How Expansion and Contraction Effect Welding Results

How metal expands and contracts when it is heated and cooled is important to everyone who welds. It determines the welding method and procedure. It also determines what jigs or work-holding devices will be required. This article explains some of the general theory and basic control procedures that the welding operator should consider on his welding jobs whether they are repair or fabrication

by L. M. Amburgey

THERE is nothing new or mysterious about the expansion and contraction of metals. Bridges and piping systems, among other structures, are built with expansion joints to allow for expansion and contraction.

The forces of expansion and contraction are so great that you cannot prevent them, but you can control them. In fact, they must be controlled and understood to do a good welding job.

The principles illustrated here will help you to understand what happens when you weld steel sheet or plate, or braze weld a casting, and why you need a jig for some jobs and partial or complete preheat for other parts.

HOW METAL EXPANDS

Expansion and contraction of metal can be controlled in one or two directions, but never in all three. Figure 1 shows what happens when a metal bar is heated uniformly without restraints:

The bar expands in all directions, shown by the arrows and dotted lines. The length, width and thickness of the bar increase as the temperature increases—the amount of increase in each direction is proportional to the corresponding dimension. In this bar, for example, the length expands three times as much as the thickness because the bar is three times as long as it is thick. As the bar is allowed to cool uniformly again, all three dimensions decrease until, at the original starting temperature, they are essentially the same as before heat was applied to the bar.

L. M. Amburgey is connected with the Linde Air Products Co., Charleston, W. Va.

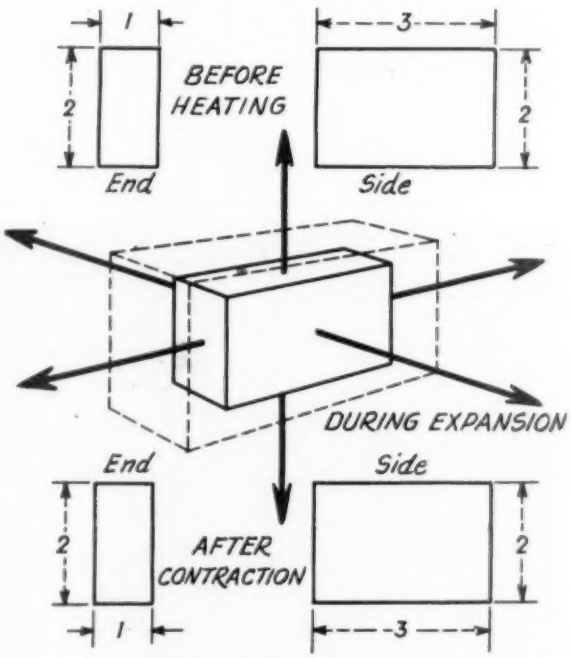


Fig. 1 When a freely supported bar is heated uniformly, it expands in all directions. When it cools, it will assume its original dimensions

CONTROLLING EXPANSION

In welding and cutting work, the metal usually is not heated uniformly. During heating the colder metal restrains the expansion of the warmer metal. Again, during cooling, cool metal will restrain the contraction of the warm metal. In effect, the cool metal acts like a force, preventing excessive expansion. We can use cold metal to help control expansion. But first, let us see what happens when expansion is controlled:

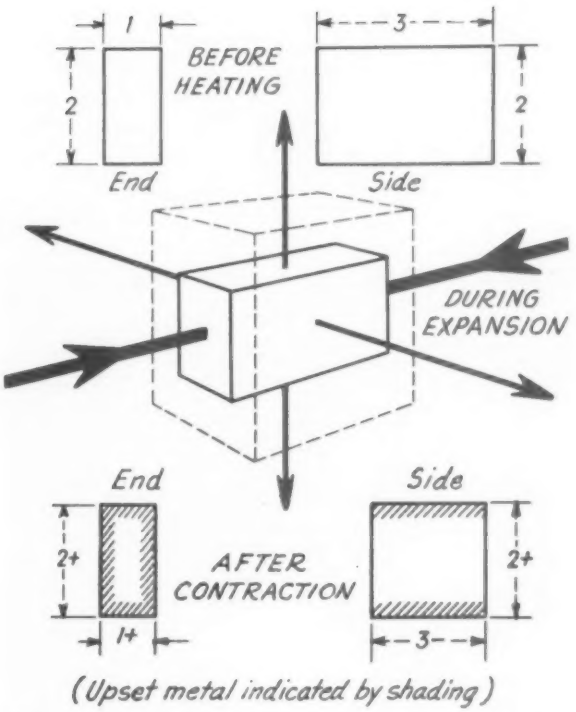


Fig. 2 Here is what happens when the bar is blocked at both ends and then heated and allowed to cool

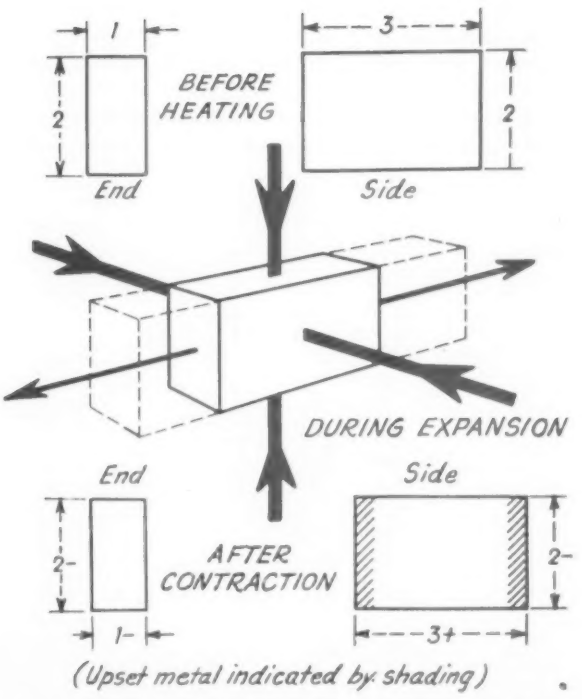


Fig. 3 When the bar is restrained from expanding in two directions, it will assume the shape shown after contraction

If the bar we used in Fig. 1 is now clamped or blocked at both ends, and then heated uniformly, only the width and thickness will increase, Fig. 2 Expansion is controlled in one direction at the expense of increased expansion in the other two dimensions. When the bar cools to its starting temperature, contraction causes all three dimensions to decrease. The fact that the bar is forcibly prevented from expanding lengthwise during heating does not eliminate subsequent contraction in this dimension. When this bar is cooled, its width and thickness are greater than originally, while its length is less.

Similarly, if the bar is clamped or restrained from expanding in two directions, it will expand in one direction when heated, Fig. 3. When the bar cools to its starting temperature, it is greater in length than it was before heating, while its width and thickness are less.

JIGS PREVENT DISTORTION

Let us see how this works by heating the edge of a piece of sheet metal. The heated area will expand in the directions shown by the arrows, Fig. 4. The sketch

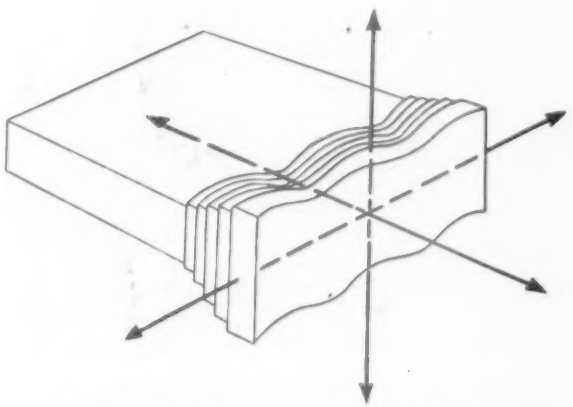


Fig. 4 The sheet is hottest at the edge with temperatures tapering off to room temperature in the unheated metal

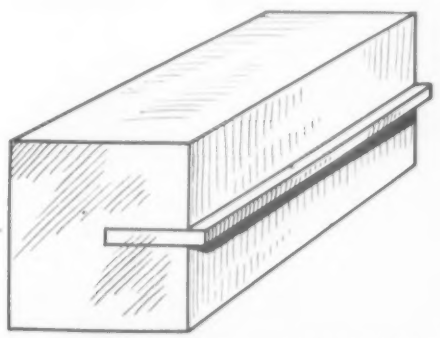


Fig. 5 If the sheet is inserted in a rigid block before heating the edge, distortion will be prevented

is greatly exaggerated to show how the amount of expansion varies directly with the temperature of the metal.

When the metal cools, the edge will be slightly shorter than before and it still may be wavy. The distortion is caused by uneven temperatures in the heated area and the restraining influence of the cold area. This distortion will happen when you weld sheet metal unless you take steps to prevent it. If you first insert the sheet in a rigid block, as shown in Fig. 5, and then heat the protruding edge, the block will prevent distortion and waviness. This illustrates why you need jigs for welding sheet metal.

Materials Handling Devices Speed Resistance Welding

USE of an air-hydraulic lift device at a spot welder at the new 19,200-sq ft Muskegon, Mich., plant of Geerpres Wringer, Inc., speeds production of commercial and industrial mop wringers and allied floor cleaning equipment.

Fig. 1 An air-hydraulic lift with 1000-lb capacity raises a tote box of wringer compartment stampings from its castered truck to workbench level to facilitate unloading for a spot-welding operation. A shaft is being spot welded into the head of a perforated mop wringer compartment in the operation shown

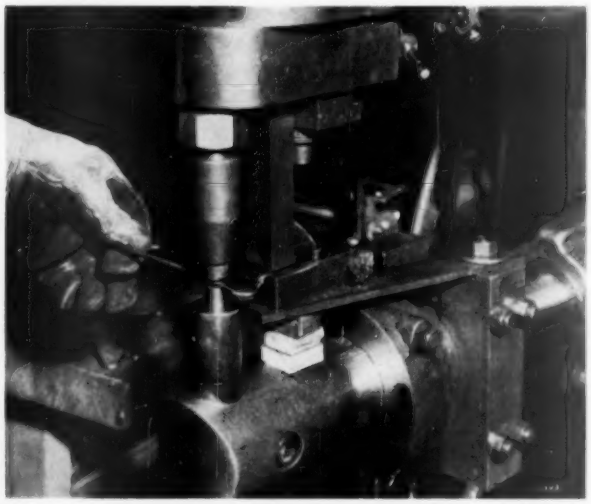
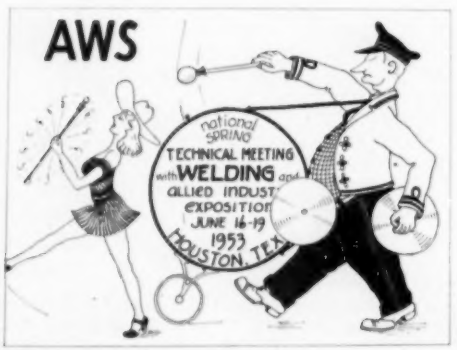


Fig. 2 After regulator springs for mopsticks are formed, they are tempered on a resistance-welding machine to relieve strains. This is an unusual application for this type of equipment

The lift device (see Fig. 1) raises tote boxes from their separate castered base and places material to be assembled by spot welding to workbench level and facilitates removal of the material from the tote box to a bench adjacent to the machine operator. Outlets for air-hydraulic lifts are provided throughout the plant.

An unusual application of a resistance-welding machine in the new plant is the tempering operation for a mop stick regulator spring (see Fig. 2). The operation relieves stresses in the spring produced during the previous forming operation. Emphasis has been placed throughout the plant on modern materials handling techniques.



AWS

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SHAMROCK HOTEL

(Technical Meetings)

and the

SHAMROCK HALL OF EXHIBITS

(Welding & Allied Industry Exhibits)

Brookhaven Cosmotron

ALTHOUGH the general public usually thinks of atom bombs when the subject of nuclear forces is raised, physicists are far more interested in learning the fundamental laws of nature governing nuclei.

In order to advance our knowledge about nuclear particles—the proton and the neutron, it is necessary to stimulate reactions which can be observed by bombarding nuclei with particles of extremely high energy. In the past, machines known as cyclotrons, or atom smashers, have been used for this purpose. These are capable of reaching energies of several hundred million volts.

Today, however, there is great interest in the billion-volt particle range. Nature already provides particles of this energy, and even higher, in cosmic rays, but they are available only at the very low rate of a few particles per minute per square inch. In order to speed up the study of high-energy physics, scientists and engineers at Brookhaven National Laboratory have teamed up to build an atom smasher of unprecedented energy. Known as the cosmotron, this machine will make available bombarding particles of hydrogen with an energy of two to three billion electron volts which will create new particles known to science as mesons. Although mesons have been studied in cosmic rays for the last ten years or so, it is only recently that scientists have been able to create them artificially.

This opens a very important field of research, as it is the mesons which are believed to hold the nucleus of the atom together. With the successful operation of the Brookhaven cosmotron, physicists are therefore confident that they will be able to solve many of the mysteries of the atom.

Here the question may be asked, why higher-energy accelerators cannot be made simply by increasing the size of the cyclotrons. It must be remembered that in a cyclotron the bombarding particle is injected at the center of a magnet with solid pole faces. As the particle is accelerated by application of higher and higher energies it moves to the periphery of the pole faces in a spiral path. Where energies of a billion volts or more are involved, the size of the solid magnet required becomes so great that its cost becomes prohibitive.

To avoid this difficulty the Brookhaven cosmotron employs a magnet built as an annular ring, popularly referred to as a "doughnut" design in which the bombarding particles move in a circular path of a constant radius. Working with a fixed radius, the magnetic field must be increased as the particle is gaining speed. To simplify the electrical engineering of the machine, the bombarding particles are preaccelerated in an electrostatic generator, to an energy of 3,500,000 v, about 0.1% of their final energy, before they are introduced into the cosmotron.

CONSTRUCTION OF MAGNET

The magnet of the Brookhaven cosmotron, the most important component of the machine, was fabricated by

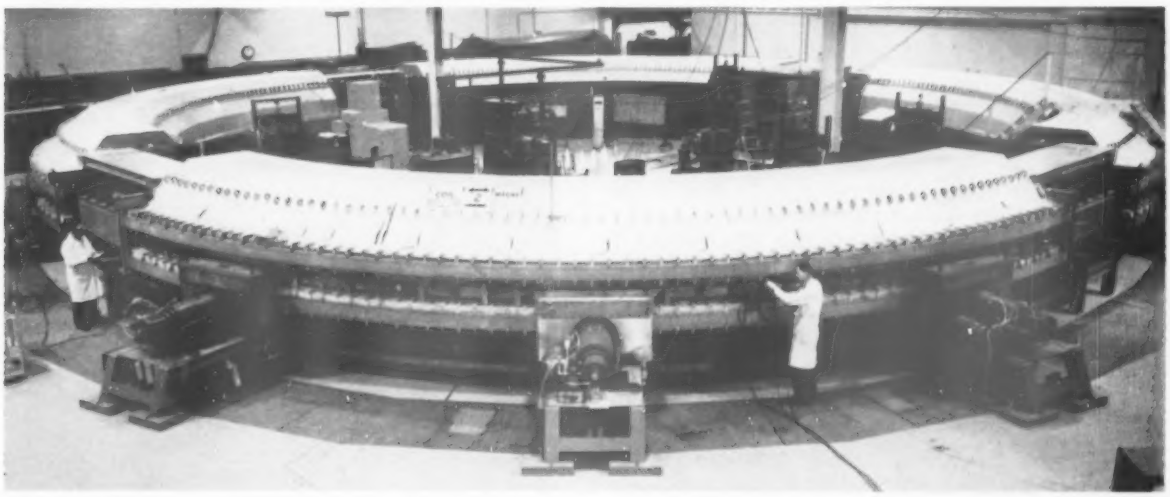

Fig. 1 General view of cosmotron, Brookhaven National Laboratory, Upton, Long Island, with the 288 blocks arranged in four quadrants

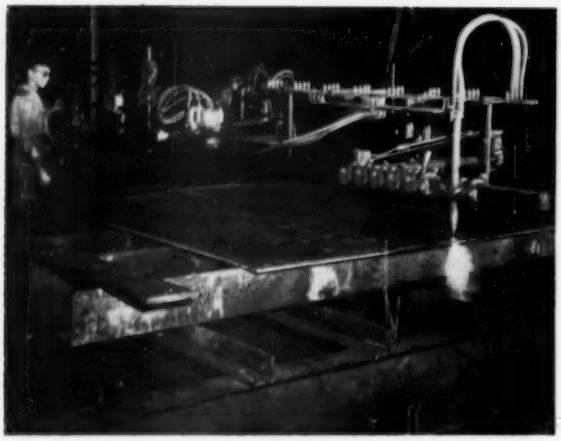

Fig. 2 Flame cutting plate to approximate dimensions

Bethlehem Steel Co., at the Bethlehem, Pa., plant. The erection was also handled by Bethlehem engineers. This magnet is approximately 75 ft in diameter, and is designed to hold the atomic particles in a constant orbit. A radio frequency system accelerates these particles around the periphery of the magnet at about 3,000,000 times a second, imparting to them a final speed closely approaching that of light.

The magnet is a circular assembly of 288 octagonal blocks, arranged in four quadrants, as shown in Fig. 1, each quadrant consisting of 72 blocks. The individual blocks were made up of 12 octagonal plates, measuring 94 in. between parallel sides. A slot, approximately $9^3/_8$ x 48 in., is cut in each plate, and the plates are so arranged that the slots form a continuous pole gap around the outer periphery of the quadrants, in which are carried the magnetizing coils and the circular vacuum chamber through which the bombarding particles travel.

The plates used in the construction of the blocks were rolled at Bethlehem's Sparrows Point, Md., plant and delivered in sizes 96 x 193 in., each sufficient for two octagonal members. The thickness was $^1/_2$ in., and the required tolerance +0.01 and −0.02 in., with preference on the minus side.

After the plates, with the gap, had been flame cut to approximate dimensions, they were ground along all edges to remove burrs. Eight stainless steel attachments were welded to one end plate in each block, to provide bases for the coil supports.

As it is of utmost importance that the magnet is dimensionably stable, it was necessary to stress relieve

Fig. 3 After flame cutting the octagonal plates are ground along edges to remove burrs

Fig. 4 Cut plates were stress relieved in car-bottom furnaces, with heavy weight to maintain flatness

the plates. This was done in a car-bottom furnace, with heavy weights placed on top of the stacks of plates to maintain flatness. Following stress relieving the face and edges of the plates were disk-ground to remove scale formed during the heating operation.

In effect the assembled blocks will act as a transformer core, and to minimize the losses due to eddy currents, insulation was provided between each plate. To check each block for "shorts" between plates an ingenious method was devised. The insulating unit used between each plate consists of two sheets of insulating fiber, each 0.006 in. thick, with a sheet of aluminum foil, 0.0005 in. thick, sandwiched between the fiber sheets. The aluminum foil is made with tabs extending beyond the edge of the plates at two points. By this method it was possible to check for "shorts" with an ohmmeter connected between plate and foil.

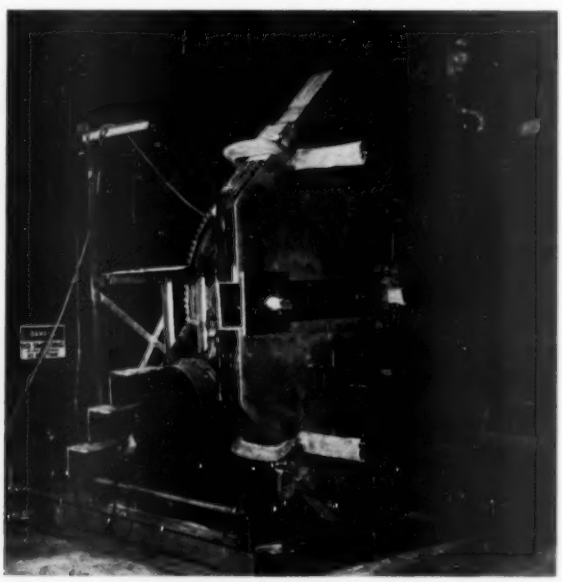

Fig. 5 Welding a block assembly

As the plates were being assembled each face was first carefully cleaned with an organic solvent to remove all foreign materials and then checked for burrs. The face was then sprayed with resinous coating to hold the insulation in place while the next plate was being placed.

After thorough testing, the plates were permanently welded into the final block assemblies using five tie bars for each block. Two of the tie bars were equipped with lifting hooks on top.

The completed blocks were machined to very critical tolerances, as the successful operation of the cosmotron depends on a very exact position of the magnetic field. This required a shaping of the gap which approaches the limit of present technical skill.

First a bevel was machined on the back edge of the blocks to allow them to nest together to the required radius of the quadrants. The face designed to serve as the base was finished on the same machine.

Next the highly accurate contour of the gap was machined. This was finished to a tolerance of 0.0005 in., with the taper not exceeding 0.2 mil per inch over the entire length. After completion of the gap the nose of the block was finished on the same machine.

Following inspection the face of the blocks was painted with regular metal primer, while the machined parts, including the slot, were painted with a rustproof compound. The rest of the surface was covered with a waterproof sealer. To prepare the blocks for shipment they were wrapped in waterproof paper and placed on wooden pallets for convenient handling.

Stainless Steel Heater Tanks Saved by Welding

by G. Bethel

PRESERVICE tests on several stainless steel tanks for bus booster heaters, revealed that more than half of them were seriously riddled with pits and holes that leaked copiously. With winter already close, the bus company found it imperative to have the tanks in operation quickly. Replacements would have taken months and there was no guarantee that identical faults would not be duplicated. The tanks were fabricated from 18-gauge Type 309 stainless to provide corrosion-free service as auxiliary heating equipment in a fleet of buses.

It was obvious that the high heat necessary in conventional welding methods had been instrumental in cracking the welded areas. An electrode was needed possessing not only an analysis comparable to stainless steel but one that could be applied easily at the lowest possible heat. This proved to be Eutec-StainTrode C. This electrode combines high-tensile strength (91,000 psi) with unusual resistance to corrosion and oxidation.

All cracked parts were cleaned and then beveled to an approximate 60 deg. vee. Machine was set at 35-amp d-c reverse polarity and a $^{1}/_{16}$-in. electrode struck on scrap metal. On the long, defective seams, the skip welding technique was used to avoid a local build up of heat. Short stringer beads of not more than 2 in. were applied, immediately quenched with water and peened. To prevent crater pin holes, the arc was drawn back and broken on the weld deposit. The booster heater on the left has had the end plate cut away to expose the inner lining.

G. Bethel is District Engineer with the Eutectic Welding Alloys Corp., Flushing, N. Y.

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(*Continued from page 131*)

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Doubles Welding Speeds with Fast Roll-Spot Technique

WITH a new technique and modified facilities, Ryan spot-welding engineers have stepped up welding speeds more than 100 per cent and, at the same time, improved weld quality. Using specially equipped machines, production is accomplishing gas-tight seam welds at 26 ipm compared with speeds of between 6 and 12 ipm formerly achieved. Spot welds on 1-in. spacings can be installed at 68 ipm in contrast to the former rate of only 21 ipm.

This accelerated performance is attained in the welding of tough stainless steels, Inconel X and W, Haynes Stellite No. 25 and other crack-sensitive alloys used in the fabrication of Ryan-built afterburners, variable nozzles, exhaust cones, tail pipes and high-temperature jet engine components.

For this work Ryan is using new seam-welding machines which have been equipped with fast-indexing mechanisms for roll-spot welding. These devices are air-operated, electronically controlled units consisting of two horizontally opposed bellows which actuate an overriding clutch. Powered by standard air line pressure of 80 psi, the clutch rotates the upper wheel electrode of the machine. By pressing a switch the continuous electric seam-welding drive mechanism of the seam welders is detached and the roll-spot drive takes over. It can be set by indicator to index in single or multiple movement and spot weld at spacings from 0 to 5 in.

The new controls are a distinct advantage over the Geneva-type drives used heretofore. With the Geneva drive, limited flexibility is available because the proportion between the dwell time and indexing time is a fixed ratio depending upon the gearing and drive mechanism. It can be varied in fixed increments only. The Taylor-Winfield air-operated drive provides infinite flexibility in varying dwell and indexing time ratios.

Although the new mechanism was developed to accomplish spaced out spot welds at increased speeds, Ryan spot-weld engineers Robert Fullerton and Fred Dever have conceived another application for it—faster seam welding. With continuous drive machines, certified, gastight seam welds could not be formed at speeds exceeding 6 to 12 ipm in the crack-sensitive alloys. When these rates were exceeded, the metal temperature rose to the point where undue shrinkage and distortion occurred and cracks developed.

Ryan Aeronautical Co., San Diego, Calif.

Fig. 1 Robert Fullerton, Ryan spot-weld engineer, adjusts the split-second action of the Taylor-Winfield control which has been accelerated for faster indexing. This air-operated, bellows-type control replaces standard electric drive for expedited work

Careful analysis of this phenomenon disclosed that it required a large number of overlapping spot welds to produce gastight seams with continuously rotating electrodes because each spot weld was inferior to that produced under static conditions. Consequently, Ryan technicians directed their efforts toward attainment of the speediest intermittent operation commensurate with high quality.

The Taylor-Winfield drive was speeded up even beyond its already rapid action. Exhaust mufflers were changed and a design which exhibited less back pressure was installed. A Ryan-improved air-intake valve, with snappier action, was incorporated. A new type of

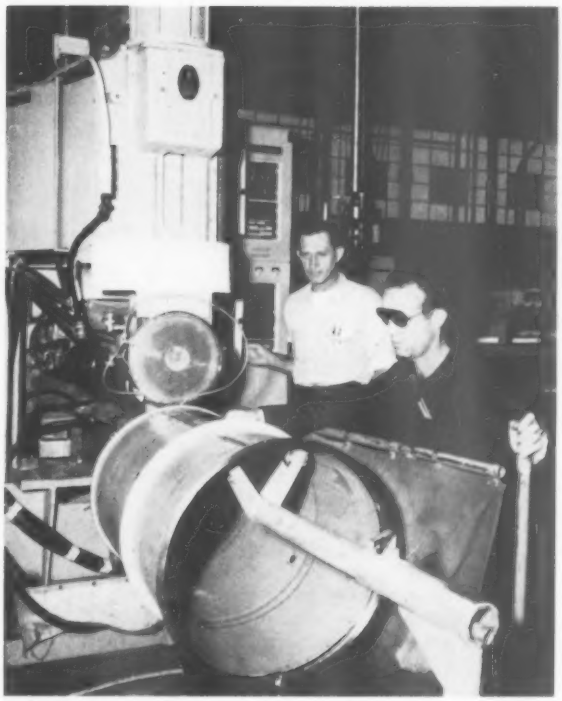

***Fig. 2** A jet tail pipe is spot welded at 68 ipm, three times the former rate, as spot-weld engineer Steve Dever (left) checks operator John Cronin on a machine which has been modified for fast welding*

faster-meshing gearing is being developed to provide more speed.

With these facilities, Ryan engineers worked out new performance ratios in which time was compressed to the minimum. Dwell time, during which the electrodes are motionless, was reduced to the shortest possible interval but kept long enough to produce sound spot weld structure. Indexing time, which is time lost in making the switch to the next spot weld location, was also cut to the bare minimum. Because of the flexibility of the equipment, these time ratios could be coordinated for different materials and thicknesses with complete freedom.

Once precision control of intermittent operation was attained it was found that better spot welds could be accomplished than under continuous operation. The spot weld nuggets were sounder because the metal was held under forge pressure during the cooling cycle and a larger, stronger nugget was made. Also, by holding the sheets during cooling, shrinkage and distortion from heat were greatly reduced.

With sounder spot welds available, it became evident that gastight seam welds could be formed with fewer spot welds and at greater speeds. This has proved to be the case. For instance, on a typical afterburner assembly formed from two sheets of 0.045-in. Inconel W, the company previously had to install 11 overlapping spot welds per running inch to form certified seams under continuous drive. Because of the proximity of the spot welds, this work could not be done at speeds exceeding 12 ipm due to the heat accumulated. With the new roll-spot technique, the company is performing certified seams with only five-and-a-half spot welds per inch and can make 26 ipm of seam.

For spaced out spot welding, the new technique is equally satisfactory. In spot welding a General Electric J-47 jet engine tail pipe the company installs 300 spot welds on 1 in. centers in one seam. These can be installed at 68 ipm of seam compared with the former rate of only 21 ipm under standard methods. With improvements now being developed, speeds of 80 ipm will be realized. This reduction in time allows the company to spot weld five of these assemblies in the same time which was required to do two with previous means.

Economically, the innovation presents an attractive picture. The Taylor-Winfield accessory drive costs about 15% of the cost of a new machine. For that amount, it is quite possible to get twice the capacity from a machine, making it perform the work of two, without devoting added personnel or floor space to the job.

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the AMERICAN WELDING SOCIETY

activities • related events

Bound Volume 1952

Bound volume of THE WELDING JOURNAL for the year 1952 are available in black imitation leather covers, together with a comprehensive subject and authors index. Price $15. This volume, comprising a total of 1200 pages in the JOURNAL and an additional 624 pages in the Welding Research Supplement, represents a veritable encyclopedia of information in the welding field. Copies may be ordered through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Western Metal Congress & Exposition

Announcement is made that West Coast Sections of the AMERICAN WELDING SOCIETY will present a comprehensive program on new developments in welding and welding equipment at the Western Metal Congress, March 23rd–27th in the new Statler Hotel, Los Angeles.

On the same dates the Western Metal Exposition in Los Angeles' Pan-Pacific auditorium will be held, with numerous welding displays included among the exhibits.

To set up the WELDING SOCIETY'S program, Herbert K. Clemens, chairman, Los Angeles Section, AMERICAN WELDING SOCIETY, has appointed a chairman and co-chairman. Respectively, these are William H. Skewis, VFP Co., and Hugo W. Hiemke, California Alloy Products Co., both of Los Angeles, who soon will announce speakers and subjects.

Clemens, who is with C. F. Braun & Co., Alhambra, Calif., also has asked E. O. Williams, Victor Welding Equipment Co., to serve in an advisory capacity.

Other technical societies which will present programs are American Society for Metals, Society for Non-Destructive Testing, American Society for Testing Materials, American Foundrymen's Society, American Society of Safety Engineers, American Institute of Mining and Metallurgical Engineers.

In addition, societies which are cooperating in sponsorship of sessions and show include American Society of Tool Engineers, American Electroplaters Society, Purchasing Agents Association of Los Angeles, Army Ordnance Association—Army Post, Pacific Coast Gas Association, American Ceramic Society, American Society of Civil Engineers and Institute of the Aeronautical Sciences—Los Angeles Section.

Admission to AWS and other technical sessions will be free to all interested parties, say officials in charge. Those who have membership cards in cooperating groups will walk straight into the exposition without formalities. Attendance will be increased by recipients of special invitations issued by exhibitors.

This year the Los Angeles exposition will be notable for innovations, such as crimson carpeting, backed by foam rubber, to make walking easy in the aisles; an industrial theater to show latest in films on welding and metal fabrication, and large blow-ups of art pieces depicting the history of American aviation from the time of the Wright Brothers to the present.

All exhibit space in the auditorium has been reserved. To accommodate additional exhibitors, Eisenman will erect a large pavilion alongside. In this, many prominent concerns will show their new developments in welding, machining, production, testing, selection and fabrication of metals.

First Meeting of Executive Committee for the year 1952–53

The first meeting of the Executive Committee for the year 1952–53 was held in the Board Room, 18th Floor, 60 E. 42nd St., New York, N. Y., on Thursday, Dec. 11, 1952 at 10:00 A.M. The following attended:

Members: Chairman F. L. Plummer, E. R. Seabloom, J. H. Humberstone, I. Morrisón, H. E. Rockefeller and M. S. Shane.

Staff: Secretary J. G. Magrath; Asst. Sec. F. J. Mooney.

Guests: G. Van Alstyne, Member 1953 Exposition Committee and Past Chairman and Member Publicity Committee; W. Spraragen, Editor, THE WELDING JOURNAL, and Director, Welding Research Council.

Welding Exposition Management

H. E. Rockefeller reported in the dual capacity of Acting Chairman of the Finance Committee (in Mr. Donald's absence) and Vice-Chairman of the 1953 Exposition Committee. He advised that the Exposition Committee, after exploration and interviews, selected Robert T. Kenworthy as Exposition Manager on a contract basis, his activity to commence immediately after Executive Committee approval. Mr. Rockefeller advised that, after review of Mr. Kenworthy's proposal, the Finance Committee had approved engagement of Mr. Kenworthy.

Action: Upon motion, duly seconded, the engagement of Robert T. Kenworthy and agreement to his proposal for serving as Exposition Manager for the AWS 1953 Welding and Allied Industry Exposition at Houston, Tex., June 16–19, in the Shamrock Hotel Hall of Exhibits, as recommended by the 1953 Exposition and the Finance Committees, was approved.

Special Committee Appreciative Discharge

The Secretary suggested to Mr. Plummer, Chairman of the Special Committee to Determine Scope, Purposes and Requirements of AWS Annual Meeting, that if he feels that his Committee has served its purpose, he recommend its discharge. Mr. Plummer so recommended. Mr. Van Alstyne, member of the Committee, agreed. Both concurred in the belief that the recommendations by the Committee, approved by the Board of Directors, were now being effected by the newly organized National Program and the 1953 Exposition Committees.

Action: Upon motion, duly seconded, the aforementioned Committee is discharged with the sincere appreciation of the SOCIETY for its excellent work.

AWS Sale of WRC Book on "Weldability of Steels"

W. Spraragen, Director of Welding Research Council, advised that the WRC Weldability Committee, as of approximately Apr. 1, 1953, will have available the subject book. WRC offers distribution through AWS on the basis of $6.50 list price, sold to AWS at a discount; providing 50 copies without charge for suitable technical magazine review. WRC is printing 5000 copies. Book contains about 300 pages, 50 of tabular matter. Project expenditure has been over $10,000.

FOR SPOT WELDING ALUMINUM

Improve quality of welds!

Increase number of spot welds before tip cleaning!

Prolong life of electrode tips!

Eliminate tedious, expensive mechanical cleaning!

DIVERSEY Pre-Welding Treatment for Aluminum

DIVERSEY No. 36 CLEANER
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Be guided by this: Companies employing the Diversey Pre-Welding Treatment report increases up to 50% in spot weld output and increases in number of spot welds made before electrode tips require redressing!

If you are looking for improved spot welds, increased production and lower costs, it will pay you to investigate the famous Diversey Pre-Welding Treatment for aluminum now . . . it's practical, proved superior, easy and surprisingly economical to use!

Diversey Pre-Welding Treatment is possible because of two outstanding Diversey developments . . . No. 36 cleaner for removing identification markings, grease, soil and No. 514 deoxidizer for removing oxide and heat scale!

A Diversey D-Man will be happy to show you the advantages of Diversey Pre-Welding Treatment for aluminum! No obligation! Write today! Complete information is available!

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Metal Industries Department

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AWS would carry inventory, purchased in lots of 500, and would be sole distributing agency with exception of orders placed by WRC contributors in large quantity lots. Mr. Spraragen stated that books not sold by AWS could be returned to WRC for refund.

Action: Upon motion, duly seconded, it was voted to accept the foregoing proposal by the Welding Research Council.

IIW Billing Change

In the order of recommendation from AWS that the International Institute of Welding change from an annual dues "post-billing" to an "advance billing" procedure, the IIW has so done. The Finance Committee approved this change.

Action: Upon motion, duly seconded, it was voted to accept and approve the IIW change in billing procedure and approve the Secretary's honoring the IIW dues invoice for 1953 year membership by payment thereof.

Increase in Journal Advertising Rates

After deliberation within Committee and disclosure that other publications were advancing their advertising rates, the Welding Journal Committee voted to raise the JOURNAL rates approximately 10% so as to change the base price for a 12 insertion page ad from $180 to $200 per month; contracts received before Mar. 1, 1953, to be honored at existing rates; "till-forbid" contracts to be honored at existing rates for balance of 1953; foregoing being usual custom in that field.

Action: Upon motion, duly seconded, it was voted to approve THE WELDING JOURNAL Committee's action as aforedescribed, to be effective as indicated.

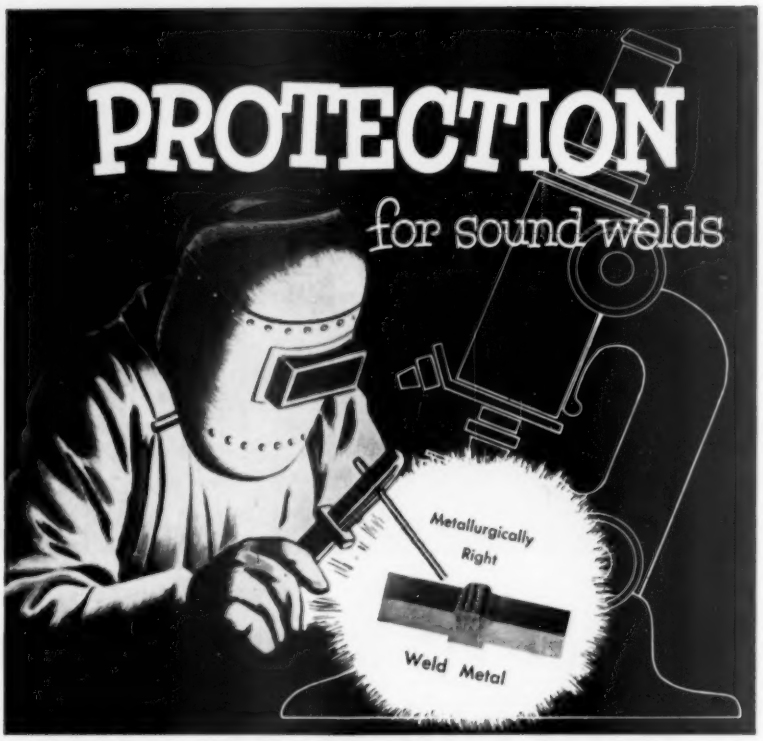
Rules of Procedure Adjustment

The "Rules of Procedure-Publication of Journal" introduction presently reads . . . "The SOCIETY shall publish and distribute free of charge to its members a monthly publication to be known as THE WELDING JOURNAL." The statement is not technically correct as post office regulations require citation of a "charge," and the SOCIETY, in conformance, states that of a member's dues, $2.50 goes to the JOURNAL. THE WELDING JOURNAL Committee desires approval to delete the words "free of charge."

Action: Upon motion, duly seconded, the aforestated recommendation was approved.

Membership Status

The Assistant Secretary reported that for the three-month period, Sept. 1, 1952 to November 30, 1952, the SOCIETY has registered a net increase of 491 members. Membership registration has been increased from 7937 to 8428. The 8428 member registration consists of 7331 active "paid-up" members and 1097 delinquent "unpaid" members. As of Nov. 30, 1951 the SOCIETY had a total registration of



Use ARCOS "Quality Controlled" Stainless Electrodes

In the split-second flash of an arc, Arcos stainless electrodes produce the "right" weld metal for the job at hand. This is the result of Arcos' experience with fabricators' welding problems . . . competent research in the behavior of various grades of electrodes in use and weld metal in service . . . a strict application of quality control in manufacture.

The value of any electrode lies in the quality of the weld metal it produces. And that's where Arcos strives to build the values that count . . . soundness, specific mechanical or corrosion resistant properties, or microstructures that can stand-up to destructive service conditions. ARCOS CORPORATION, 1500 South 50th St., Philadelphia 43, Penna.

Use ARCOS Low Hydrogen Electrodes

ARCOS GRADE	A.W.S. SPEC.
Tensilend 70	E7016
Tensilend 100	E10016
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Manganend 1M	E9015
Manganend 2M	E10015
Nickend 2	E8015
Chromend 1M	E8015
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When you can deposit sound weld metal without changing electrodes to meet different welding positions—and use the same electrode on A-C or D-C current—you're saving time and inconvenience. With few exceptions, all types of Arcos Low Hydrogen Electrodes offer this advantage on a variety of base metals. That means a smaller inventory, since you can safely weld many jobs from start to finish with ONE ELECTRODE. Because Arcos Low Hydrogen Electrodes are "quality controlled," there's no danger of underbead cracking.
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Specialists in Stainless, Low Hydrogen and Non-Ferrous Electrodes

7499 consisting of 6471 active members and 1028 delinquent members.

Committee Chairmen Invitations

Upon inquiry the Secretary advised that the President had approved the extension of invitation, during his term, to the Chairman of the National Membership Committee to attend the meetings of the Board of Directors. He advised that the previous Board had voted to extend a like invitation to the Chairman of the Technical Activities Committee when there were TAC items on the agenda.

Action: Upon motion, duly seconded, this Executive Committee approved the extension of invitation to the Chairman of the Technical Activities Committee to the Board of Directors' meetings this year.

Reciprocal Membership

R. L. Townsend, Chairman of the National Membership Committee, and Associate Member of the National Welding Supply Association, suggests reciprocal membership across and through the Secretaries of the AMERICAN WELDING SOCIETY and the National Welding Supply Assn. The developing of closer relationship in the order of common interest in exposition could indicate advantages to both organizations therefrom.

Action: Upon motion, duly seconded, the suggestion was referred to the Constitution and By-Laws Committee for (*a*) submission of their recommended wording for a By-Law provision allowing for reciprocal membership in such organizations, through the respective Secretaries,[5] and (*b*) their Committee's opinions regarding the advisability, advantages or disadvantages of the suggested membership exchange pattern.

Standing Committee Appointments

The Secretary presented Attachment No. 12, a group of new appointments, approved by President Plummer, not cleared before the last meeting of the Board of Directors.

Action: Upon motion, duly seconded, the persons listed in Attachment No. 12 were approved for appointment to the respective Standing Committees, subject to acceptance by appointees.

Next Meeting

It was agreed to schedule the next meeting of the Board of Directors on Friday, Feb. 20, 1953, in Baltimore, Md., such to be preceded by a meeting of the Executive Committee in Baltimore on the day preceding, Thursday, Feb. 19, 1953, for the reviewing of Board of Directors' agenda, which will also serve as the Executive Committee agenda. February 20th is the regular meeting date of the Baltimore (Maryland) Section. The Secretary is to invite the Maryland and surrounding AWS Section officers to attend the Board meeting on the 20th. All foregoing subject to making satisfactory arrangements therefor.

NEW LITERATURE

Hobart Arc Welding News

Volume IX, No. 4, "Hobart Arc Welding News," a 20-page booklet of interesting photographs and articles on welding from all over North America, is now available. Copies are mailed free of charge to anyone interested in arc welding.

Many of the articles feature time- and money-saving applications. To get your copy, write the Hobart Brothers Co., Troy, Ohio.

Metallizing Cuts Salvage Time

A large automotive manufacturer formerly used welding to build up areas of crankshafts which had been mis-machined to a smaller dimension than required for assembly. The high temperatures risked warping the parts. Salvage with welding required at least one hour per part.

They now use metallizing and the same salvage operation requires only 5 to 10 min. per shaft, including preparation of the surfaces to be sprayed. Preparation for the metallizing process is very simple, the newly machined parts require only a "shoe-shine" with a strip of emery cloth. A high molybdenum metallizing wire is then sprayed on, which is said to provide a harder surface than the original shaft material. Since only about 0.025 in. is usually required for finish allowance, this part of the salvage process requires less than one-tenth the time required for finishing after build-up by welding.

Another user reported a saving of $7200 per year by metallizing worn press blanket cylinders. This is only one metallizing application of many which saves this user many thousands of dollars.

These and many other money-saving stories appear in Vol. 6, No. 5 of the *Metco News*. Get your copy by writing to Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

Control of Electric Motors

by Paisley B. Harwood

Since the use of electric motors in all phases of industry has expanded so greatly, the development of controlling devices for these motors has followed suit. This book has been revised and expanded to keep pace with the latest developments and to present the most up-to-date information available on the design, construction and application of controllers for all kinds of motors.

This book is published by John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y. The price is $7.50 a copy.

Dot Welding Booklet

A new 8-page booklet is available describing the Dot Weld process and the advantages of this proved low-temperature welding process for reclaiming castings. Contains full information on equipment, cost and case histories. Available from Metallizing Company of America, 3520 W. Carroll Ave., Chicago 24, Ill.

Sprayweld Process

A newly revised 4-page two-color illustrated bulletin describing the Colmonoy Spraywelder and Sprayweld Process is now available from Wall-Colmonoy Corp., 19345 John R St., Detroit 3, Mich.

The bulletin describes and illustrates latest developments in Spraywelding equipment and techniques that enable powdered Colmonoy hard-facing alloys to be fusion bonded to metal parts by a three-step process to provide nonporous, wear, heat, erosion and corrosion-resistant surfaces.

Properties of three Colmonoy alloys which are adaptable to Spraywelding and have Rockwell C hardnesses ranging from 35 to 61 are given in the bulletin.

Other illustrations show water turbine pump sleeves, acid sludge pump components and petroleum industry thermowells, all of which have been Spraywelded to resist wear and corrosion. A list of typical Sprayweld applications in the new bulletin includes parts used by the following industries: Agricultural, Aircraft, Automotive, Brick and Clay, Cement and Stone, Ceramic and Glass, Chemical, Construction, Drug, Electrical, Food and Dairy, Marine, Materials Handling, Metalworking, Mining, Petroleum, Railroad, Rubber and Woodworking.

Stud Welding Manufacture

An illustrated, 8-page booklet describing their new plant and unusual production facilities is being offered by KSM Products, Inc., Merchantville, N. J. This manufacturer of studs and equipment for electric-arc stud welding has been able to keep prices down in spite of rising costs, and the booklet tells how savings through engineering and production are achieved.

"This Stands Behind Your KSM Stud Welding Order" contains interesting photos showing production of cold-rolled threaded studs, manufacturing, storing and shipping facilities and various studs and stud welding equipment.

For your free copy, write KSM Products, Inc., Merchantville, N. J.

Practical Applications of Metallizing

New general bulletin on metallizing covers a wide range of practical applications of the process in machine element maintenance and repair, production, production salvage and corrosion prevention. The 8-page, illustrated bulletin discusses the characteristics of sprayed metal, describes in general where metallizing is used, its general advantages and limitations. Some of the jobs illustrated include the repair of worn crankshafts, pump packing sleeves, press rams, turbine rotors and stators, rolls, motor shafts, pistons, cylinders, etc. Other applications described include the repair of blow holes in castings, the use of the process in brazing and soldering, electrical shielding and circuits, in model work, molds for plastics, and in glass and ceramics.

This bulletin, 51A, also includes a number of case histories which describe in detail the savings in time and money effected on various typical metallizing jobs. For instance, a typical application is that of a user who saved $9500 in eight months on metallizing worn grinder spindles. In another instance metallizing saved $1750 on seven agitator shafts.

The bulletin also describes the use of metallizing in corrosion protection on structures and equipment, such as tanks, gas holders and capacitor cases.

The equipment required for metallizing is described and a typical installation is illustrated.

There is no charge for this bulletin and a copy may be obtained by writing Metallizing Engineering Co., Inc., 38-14 30th St., Long Island City 1, N. Y.

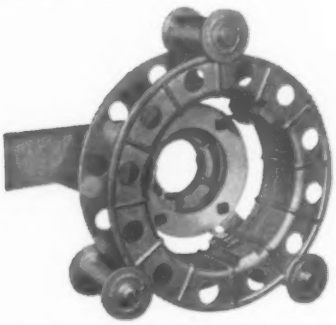
NOW

Double and Triple weight coils for automatic welding with the new REID-AVERY (free wheeling) REELS for Submerged Arc, Open Arc, and Gas Shielded Arc Welding

Raco Reel for 150-200# coils with floor mounting stand.

Decrease down-time by using larger coils. Machines now equipped for 25 lb. coils can use up to 75 lb. coils with these new reels.

These cast aluminum alloy reels ride on ball-bearing trunnions with deep flanges. The wire uncoils with remarkable ease and yet there is no chance of overrunning and throwing loops over the side. No brakes or drags of any kind are necessary. The wire itself prevents overrun. These "free wheeling" reels provide the absolute minimum load on the automatic welding machine.



Raco Reel for 25#-50#-75# coils. Mounted on popular submerged arc machine.

The Reid-Avery reels are available with stands for floor mounting or with special spiders for direct attachment to most popular automatic welding machines. Three reels 12" ID x 4" wide, 14" ID x 6" wide, and 25" ID x 4" wide nominal size are in stock for prompt delivery.

Raco Reel shown split for loading.

Note the simple split reel construction with suitcase type latches. Coils can be replaced in seconds and no wrenches or special tools are required.

We are equipped to supply all sizes of layer wound coils for these reels, for other reels, or on expendable wooden spools where required.

The REID-AVERY COMPANY

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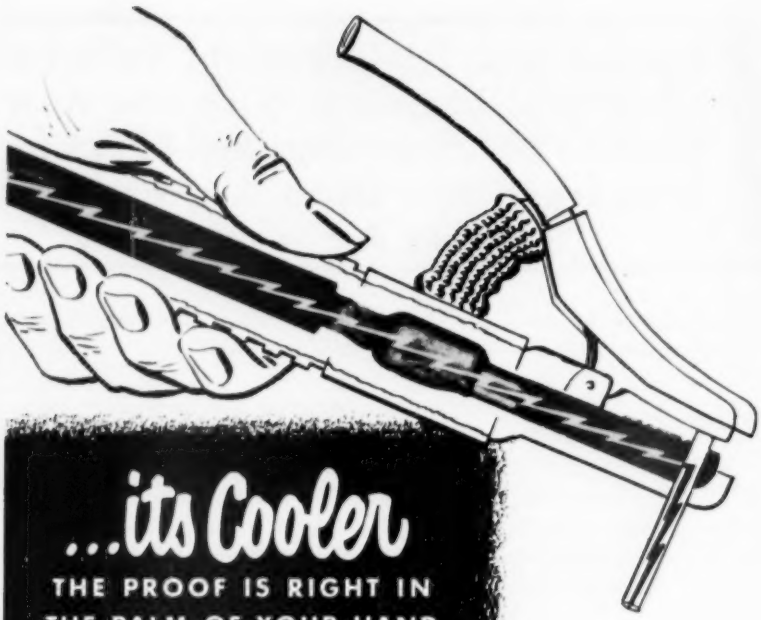
SINCE 1919 PRODUCERS OF ARC WELDING ELECTRODES AND WELDING RODS



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CADDY®

ELECTRODE HOLDER

FULLY INSULATED MODELS

500 AMP

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OTHER MODELS ON REQUEST

FEATURES:

- CADWELD connection—cable to jaw is a 100% conductivity solid copper connection. It is permanent—cannot melt out, burn out, loosen or corrode.
- Short completely replaceable beryllium copper jaw has 80% conductivity.
- Lightweight durable steel body carries no current.
- Cable gripper prevents broken strands and flexing at the connection.
- Operator's hand is over fully insulated cable, air space and handle ribs.
- Fiberglass spring cover withstands 1200° F. heat radiation from the arc.
- NO Shocks—Handle screws eliminated.
- Replaceable fiberglass insulators.

"CADDY" ARC WELDING ACCESSORY DIVISION

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Flame Cutting

A truly revealing and instructive booklet on flame cutting has been published by National Welding Equipment Co., 218 Fremont St., San Francisco 5, Calif.

The brochure tells the novice and beginner how flame cutting works. It aids the vocational instructor in teaching this subject. The brochure also gives many of the younger salesmen in our industry a better understanding of the process of flame cutting in general and of the construction of the torch, they are to sell, in particular. It offers the buyer a chance to actually know how the torch is designed and constructed and *why* it is so built. It offers even to the experienced operator much data which he might have forgotten or been seeking for some years to have explained to him.

Tempil° Pellets

Tempil° Corp., 11 W. 25th St. New York 10, N. Y., has compiled a bulletin, *Instructions for Using Tem, il° Pellets*, containing a number of helpful suggestions for the use of Tempil° Pellets in a variety of applications.

The special problems discussed include: The use of Tempil° Pellets in heating cycles of long duration; the effect of special atmospheres; the use of miniature Tempil° Pellets inserted in sealed cavities (as in determining attained temperatures in jet engines); techniques for improving observation within a brightly radiating furnace.

Refinery Under Construction

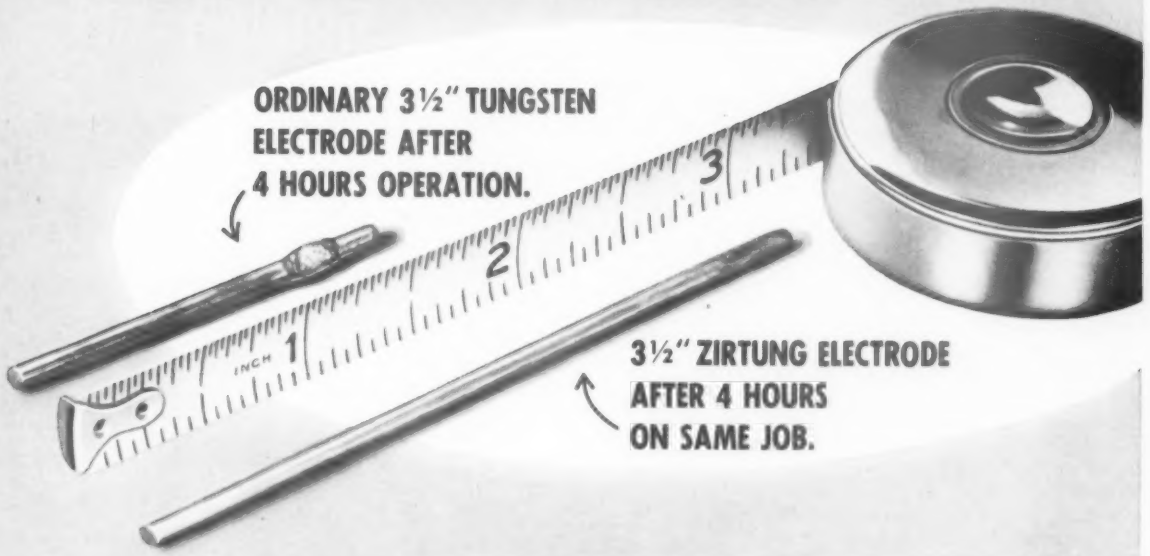
The complex task of erecting a modern refinery is dramatized in a four-color drawing of the job site featured in the most recent issue of the *Kelloggram*, just published by The M. W. Kellogg Co., refinery and chemical plant engineer-contractors of New York City.

Bringing you to the site at a time when the job is about 75% complete, the detailed drawing depicts an imaginary 100,000-bbl-per-day refinery and integrated petrochemical plant. It reveals the myriad activities involved in bringing blueprints to reality. It shows welding, radiography, fabricating, guy derricks in action, heat treating, structural steel work—units on stream—in short, the mammoth job from the ground up.

Other portions of the publication deal with the organization of Kellogg's Construction Department and how it directs the erection of refinery and chemical plants in all parts of the world.

This construction program currently entails the control of nearly two score major tasks in the United States, Canada, England, Europe, Africa, Australia, South America and the Near East, as well as a number of power and process piping jobs and refinery renovations.

ZIRTUNG Beats 'em all



ZIRTUNG STANDS OUT BECAUSE IT *STANDS UP!*

Why Zirtung Saves Time and Money

1. **Greatly reduced electrode consumption.**
2. **Far less contamination from material being welded.**
3. **Self cleans contamination without loss of electrode.**
4. **Greater arc stability.**

Far outlasts ordinary tungsten electrodes!

The photo tells the story! The ordinary tungsten rod lost 2 inches in four hours. But ZIRTUNG, on the same job in the same time, lost *only ½ an inch!*

An exclusive Sylvania Development

This time-saving, money-saving rod is an amazingly improved tungsten-zirconium alloy, developed exclusively by Sylvania for inert gas electric arc welding. Operates in the same current ranges as thoriated tungsten. And it contains no radio-active material.

You'll find Zirtung great for mild steels, aluminum and magnesium. So order Zirtung today! Your nearest Sylvania Welding Distributor is the man to call. He also handles Sylvania pure tungsten and thoriated tungsten electrodes. For further information address: Sylvania Electric Products Inc., Dept. 3T-4902, 1740 Broadway, New York 19, N. Y.

SYLVANIA

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PERSONNEL

Leach Named Manager

A. F. Leach has been named manager of renewal parts sales for the General Electric Co.'s Welding Department, it was announced by C. I. McGuffie, the department's manager of marketing. He will be succeeded in his former position as manager of electrode sales by Arthur Ward, Mr. McGuffie said.

Mr. Leach, a native of Texas, was graduated from the University of Texas in 1941 with a BSME degree and joined G-E the same year. He served on the company's test course for two years and joined the Welding Department in October 1943 as an application engineer. In 1945 he became the welding sales engineer on electrodes in the G-E Southwest and Rocky Mountain Districts. He was transferred to Fitchburg in 1950 as electrode sales engineer, the position he held at the time of his present appointment. He is an AWS member.

Mr. Ward comes from Leominster, Mass. Following six years in the Navy Hospital Corps during World War II, he sold drugs and chemicals in Virginia and Massachusetts for two years. He received a B.S. degree in chemistry from the University of Massachusetts in 1950, and early in 1952 became a member of the G-E Welding Department production group.

Both appointments are effective immediately.

Ballentine Named Manager

Richard E. Ballentine AWS has been appointed plant manager of the new welding-electrode plant being constructed at Montevallo, Ala., by the Westinghouse Electric Corp.

The announcement was made at a recent luncheon meeting of business and civic officials of Montevallo, where detailed plans for the new plant were revealed by Tom Turner, vice-president in charge of the Westinghouse Motor & Control Division, Buffalo, N. Y.

Until completion of the new plant, which is expected in September 1953, Mr. Ballentine will continue in his present function as development engineer on brazing alloys for the Motor & Control Division.

Mr. Ballentine has been associated with Westinghouse since 1940 when he joined the Westinghouse Research Laboratories in Pittsburgh. He was promoted to his present position in 1946.

Born in Cleveland, Ohio, Mr. Ballentine attended the Carnegie Institute of Technology and specialized in metallurgy studies. Prior to joining Westinghouse he was associated with the Otis Steel Corp. for six years.

O. T. Barnett Joins A. O. Smith

O. T. Barnett has joined the Welding Products Division of the A. O. Smith Corp., Milwaukee, Wis. Mr. Barnett has been appointed Central District Sales Manager and operating out of Chicago he will supervise the sale of welding products in Wisconsin, Minnesota, Iowa, Kansas, Missouri, Illinois, Indiana, Ohio, Kentucky and Michigan.

Mr. Barnett has been associated with the welding industry since receiving his degree in Chemical Engineering from Armour Institute in 1933. Recent business associations in the welding field have

been with the Metal & Thermit Corp. in Pittsburgh and as co-owner of his own business in Chicago.

Mr. Barnett is a member of the AMERICAN WELDING SOCIETY and the American Iron and Steel Institute. Many of Mr. Barnett's articles on welding have been published. He has been a frequent speaker before welding groups throughout the country.

Bartz Made Welding Supervisor

Edgar W. Bartz has been appointed Pacific Coast District welding supervisor for Westinghouse Electric Corp.

Mr. Bartz has been an electric welding specialist for 14 years, half of that time guiding western industries and shipyards as a welding application engineer for Westinghouse. He is second vice-president of the San Francisco Section, AMERICAN WELDING SOCIETY, and formerly served as the section's treasurer and publicity chairman.

Mr. Bartz's headquarters will continue to be at 410 Bush St., San Francisco. He lives at 372 Lexington Way, Burlingame.

At the same time, Mr. Maytham announced the appointment of Wayland A. Heding as welding application engineer in the Los Angeles office, serving southern California and Arizona. Mr. Heding held a similar position with Westinghouse in its Milwaukee, Wis., office since 1950 and formerly was a salesman for the Harnischfeger Corp.

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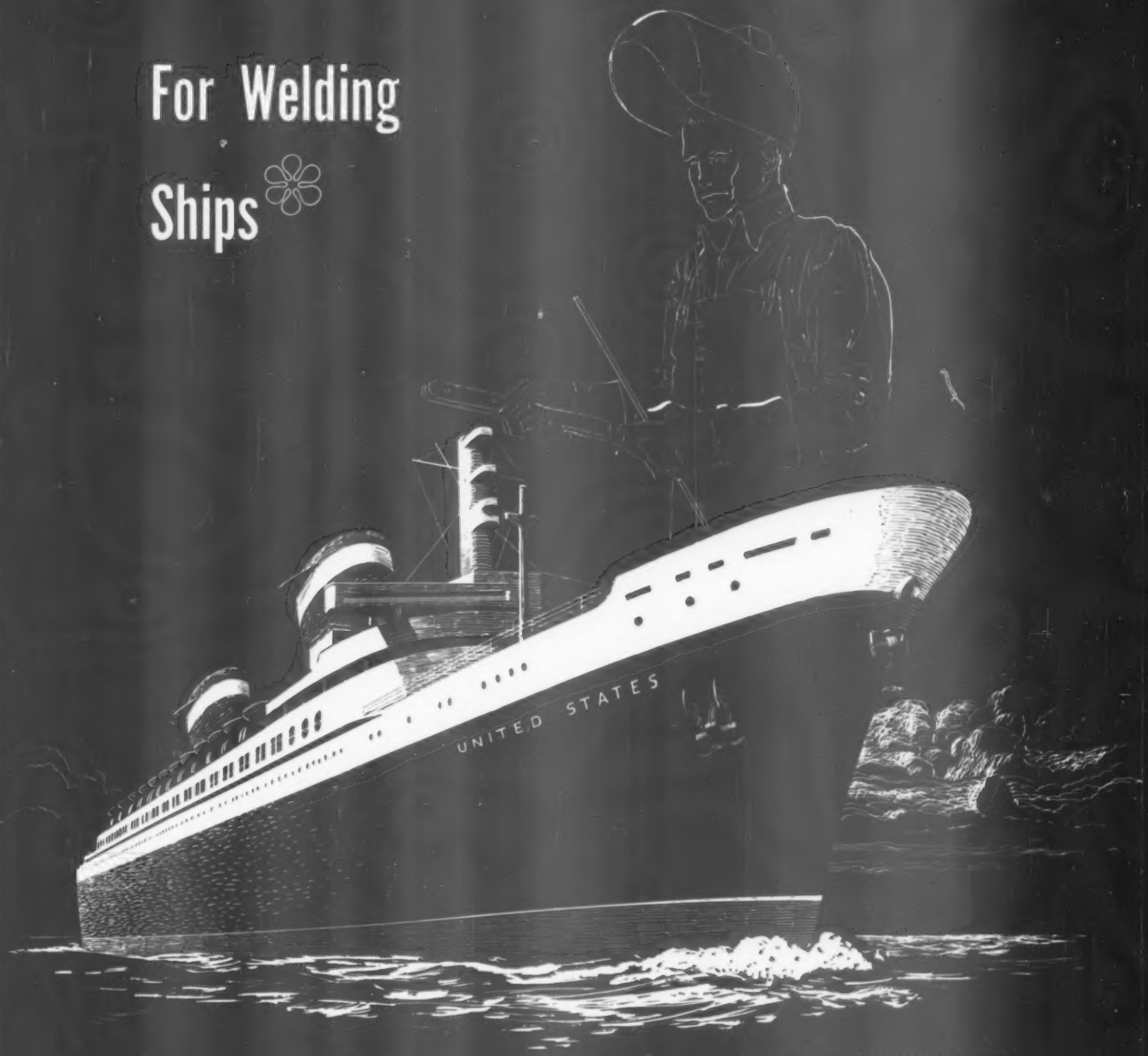

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NEWS OF THE INDUSTRY

Western Metal Exposition and Congress

Enlarged beyond original plans, the Western Metal Exposition, March 23rd–27th in Los Angeles, has attained standards and dimensions which make it the largest and most important display of metals and machinery yet blueprinted for the Pacific Coast.

Committees in charge made this statement with the declaration that 271 firms have entered exhibits. So many concerns are in the show that the exposition will be held under two roofs—Pan-Pacific auditorium and adjacent Pan-Pacific Pavilion to be connected with runways. On the same dates technical sessions of the Western Metal Congress will take place in Los Angeles' new Statler Hotel.

"Faster and better production at a less outlay of capital" will be the theme of many displays, said William H. Eisenman, secretary, American Society for Metals, now in Los Angeles to operate the combined exposition and congress.

A show feature will be a large display of machine tools made in Great Britain, Switzerland, Norway, Sweden, Austria, France, Italy and Japan, Eisenman said. Lathes, boring mills, jig borers, radial drills, tool grinders, milling machines, chucks and centers will be shown in operation.

Metals, machinery, metal fabricating equipment and methods, as well as equipment for research, testing, inspection, heat treating, welding, cutting and otherwise handling metals will be seen throughout the exposition.

Many of the country's best technical engineers will be stationed in displays to undertake solutions of industrial problems by new approaches, utilization of better metals and machinery or advanced techniques.

Twenty western divisions of national technical societies are cooperating with American Society for Metals in sponsoring the Exposition-Congress.

Six will present technical sessions during the five-day meetings. These are American Society for Metals, American Welding Society, Society for Non-Destructive Testing, American Society for Testing Materials, American Foundrymen's Society and American Institute of Mining and Metallurgical Engineers.

Other societies' western sections which are cooperating along other lines are: American Society of Mechanical Engineers—Southern California section, American Society of Tool Engineers, Institute of the Aeronautical Sciences—Los Angeles section, Army Ordnance Association—Army Post, Purchasing Agents Association of Los Angeles, American Society of Heating and Ventilating Engineers, American Electroplaters Society, Society of Automotive Engineers, California Society of Professional Engineers, American Society of Civil Engineers, Structure Engineers Association of Southern California, American Society of Safety Engineers, American Ceramic Society, Pacific Coast Gas Association.

ASM Congress sessions will be devoted to titanium, zirconium, aluminum, magnesium and other alloying materials.

Information on zirconium was obtained under special projects of the Atomic Energy Commission. For a time it was kept under wraps. Only recently the commission lifted its restriction and asked ASM to make the zirconium data available to all industry.

All types of welding for aircraft, rockets, guides missiles and other applications—including gas, arc, spot, seam and fusion welding—will be discussed at sessions of the American Welding Society.

SNT and ASTM technical sessions will have recent developments in x-ray, electronic, supersonic, electron-microscopic and other testing methods. Late technique for casting ferrous and nonferrous materials will be described at AFS meetings.

An industrial theater will show films on late developments in machining, testing and otherwise producing, fabricating and applying metals.

Exposition gates will admit without charge those who show membership cards of cooperating societies or special invitations issued by exhibitors. Others may enter on a registration fee of $1. Congress sessions will be open to everyone.

Heavy Industry Section at British Fair

Firms exhibiting in the heavy industry section at the British Industries Fair this spring will welcome U. S. buyers to their displays. Many are now selling their products in the United States, and all will be showing new items on their stands at Castle Bromwich, Birmingham (England) between April 27th and May 8th.

The biggest section of the entire B.I.F. will be the Engineering Section. Nearly 500 manufacturers have already taken space totaling over 150,000 sq ft.

Training Advanced Welders

During the 1952 term, a total of 562 advanced welders were trained in the Eutectic Welding Institute's classes in Flushing, N. Y., and its new West Coast school which graduated its first group in September. The Institute's training program, a continuing service of the Eutectic Welding Alloys Corp., is considered unique in the welding field since it trains only advanced welders in the most modern welding techniques by means of "conference type" practical training "clinics." By immediately following a short lecture period with detailed practical demonstrations, in which the students join, the welders actually use new labor- and time-saving welding methods to solve problems they may have encountered in the field.

In order to maintain such close instructor-student relationships, providing individualized and personalized instruction for each advanced welder, the classes are limited in size. Each course takes a full week, with classes held every two weeks throughout the entire year.

Even after they graduate, it is reported, the advanced welders turn to Eutectic's tremendous storehouse of knowledge to provide the answers to their welding problems. Many a graduate of the Institute has breezed through a seemingly "impossible" welding task merely by following the detailed instructions airmailed to him.

The Eutectic Welding Institute's 1953 term has its first class scheduled for January 12th. Detailed subject outlines, schedules and other data on these highly informative courses may be had by writing to Eutectic Welding Alloys Corp., Dept. P, 172nd St. at Northern Blvd., Flushing 58, New York, N. Y.

Eutectic Announces 1953 Prize Competition

New rules have been announced for the $2000 prize competition for "Contributions to the Science and Art of 'Non-Fusion' Welding, Brazing and Soldering," by Eutectic Welding Alloys Corp., Flushing, N. Y.

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FOR MINIMUM PRESSURE DROP

THIS TUBE-TURN Welding Elbow has full radius conforming to A.S.A. Standard B 16.9. The radius is not reduced by tangents. The interior walls are consistently smooth and perfectly circular . . . important production features which minimize pressure drop.

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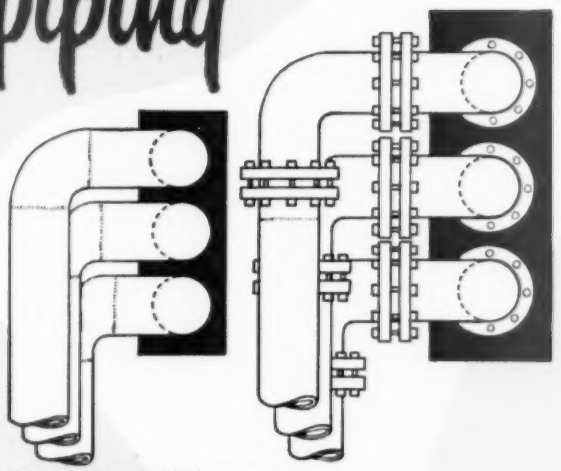
COMPACT WELDED PIPING SIMPLIFIES THE JOB

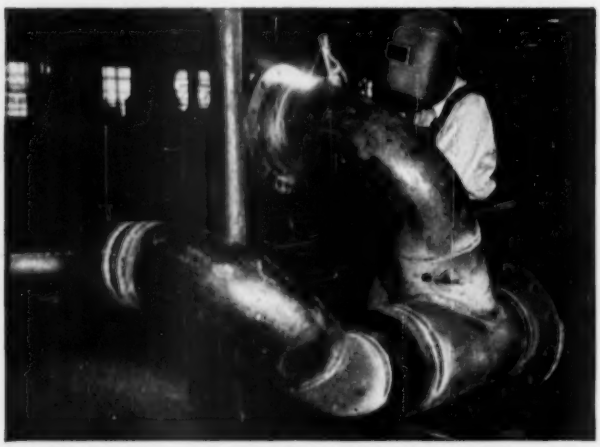
COMPACT *Welded piping* SIMPLIFIES THE JOB

You can simplify design, save valuable space and speed up the piping job by specifying *welded construction* with Tube-Turn Welding Fittings. Welded joints are virtually flush with the pipe. Pipes can fit snugly together in tight corners . . . against wall or ceiling . . . or around equipment. And welded piping requires little elbow room to install . . . and to insulate. The true circularity and uniform wall thickness of Tube-Turn Welding Fittings simplifies fit-up and assures a job well done under crowded working conditions.

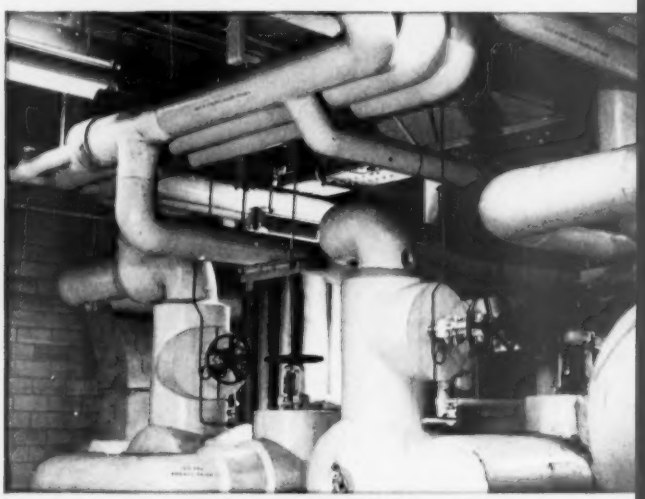
This is just one reason why it pays to specify *welded piping*. It's stronger, lighter, streamlined, economical to install, insulate and maintain.



Example: The welded assembly on left takes a third less space than comparable flanged assembly.



Bring on your tight corners! Entire sections of welded piping can be shop-fabricated and erected as a unit with a few simple tie in welds or flange connections to valves or containers.



In the new O. H. Hutchings Station of Dayton Power & Light Company. Piping for deaerators and feed water heaters is compact, streamlined and permanent. Directional changes are made with TUBE-TURN Welding Fittings.

Want Dimensional Data?

Tube Turns, Inc. has compiled a handy folder of piping dimensions and weights of TUBE-TURN Welding Fittings and Flanges. If you'd like a free copy, just send this coupon.

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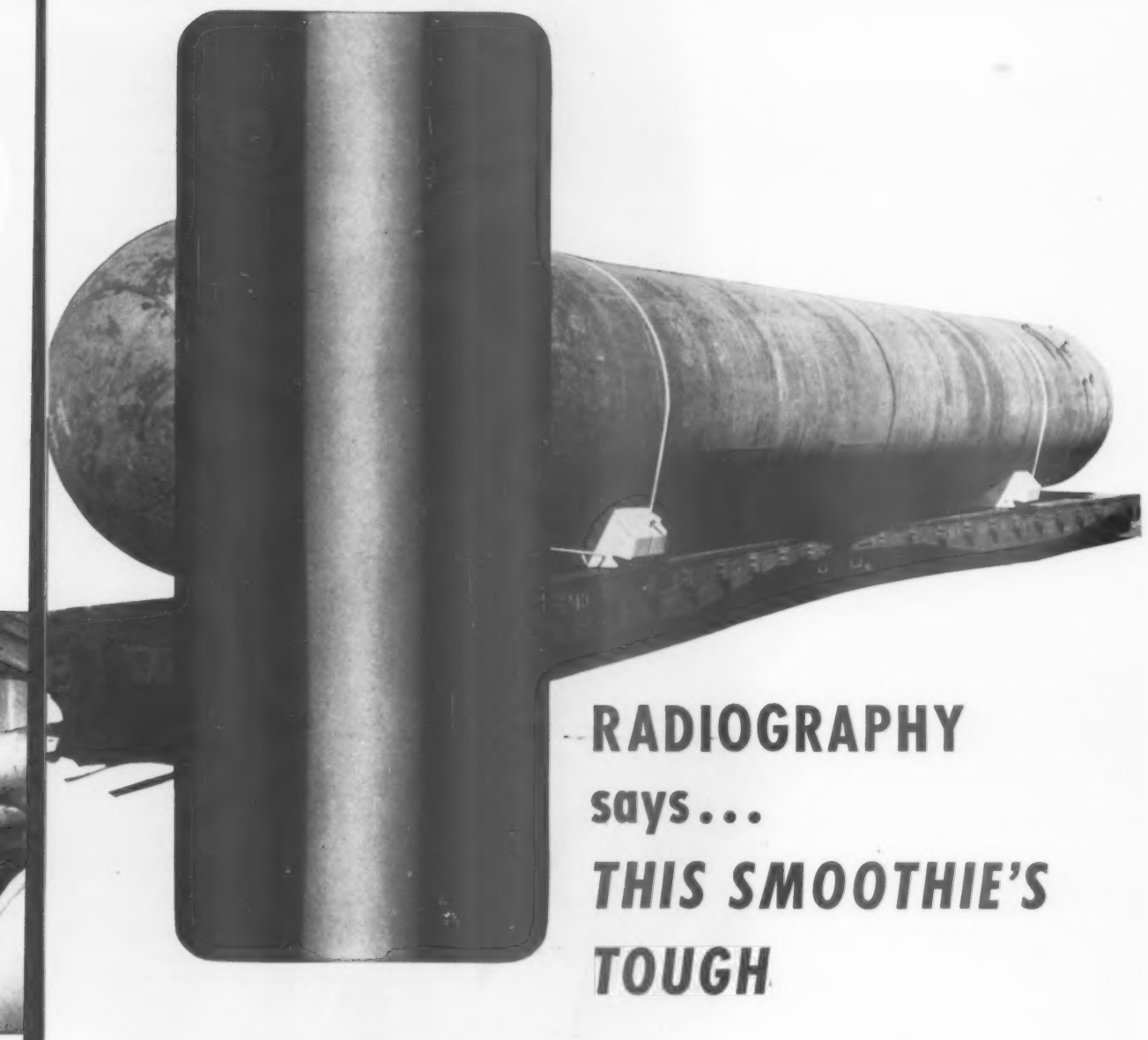

RADIOGRAPHY says... *THIS SMOOTHIE'S TOUGH*

This 90-ft. pressure vessel looks smooth, clean, and neat. But that's not all that welding did for it. It helped make the tank strong and tough with less weight and at lower cost.

Designers of pressure vessels can take full advantage of the welding process because each weld can be proved sound by radiography.

This is how radiography widens the opportunities for welders—why it can increase your business.

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PAGE Welding Electrodes AND Rods

Once again, Eutectic's contest is open to engineers, metallurgists, research investigators, welders, students, faculty members and all others qualified.

Additional emphasis in the 1953 competition, however, has been placed on papers of a more technical nature and the scheduled cash awards have been revised to provide greater reward for entries in that category.

As in previous years, a second category has been established with $550 in cash awards for "Practical Welding Applications."

A complete set of contest rules together with "Helpful Hints for Contestants," a bibliography, etc., can be obtained by writing to Eutectic Welding Alloys Corp., Department P, 172nd St. and Northern Blvd., Flushing 58, New York, N. Y.

Training Course for Cobalt-60

An intensive, two-day training course, designed to provide the basic knowledge needed to utilize Cobalt-60 sources in industrial radiography, is now being offered by Tracerlab, Inc., 130 High St., Boston, Mass.

The course has been made necessary, the firm announced, by the growing use of Cobalt-60 as a nondestructive testing means, and the inability of industry to obtain competent radiographers skilled in the use of gamma radiation.

The course of study covers such topics as radiological safety, handling of sources, techniques of exposure, the use of films and screens, use of radiation survey meters, actual practice in exposing, developing and evaluation of film, and other pertinent aspects of industrial radiography.

Inquiries concerning the program may be directed to either Boston, or to Tracerlab, Inc., 2295 San Pablo Ave., Berkeley, Calif., where the same program will also be given.

German Welding Equipment

Welding equipment of German design is now available from a new firm, the American Messer Corp., recently organized as the affiliate and sole American representative of Adolf Messer, G.m.b.H. of Frankfurt, Germany.

The American firm is essentially an engineering firm and handles the full line of Messer equipment incorporating a complete line of gas and electric welding equipment, automatic cutting machines, oxygen plants and acetylene generators.

The German firm was widely known to the welding industry in the USA prior to World War II, and some 130 Messer oxygen plants are operating throughout the country.

the unseen MR. "X"

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WELDING AND CUTTING EQUIPMENT

BURDOX

Provides every product...every process... to fit every purpose best

We call him Mr. "X"—not because he is an unknown quantity but rather because he represents an idea, a tradition, a way of doing business. Mr. "X" stands for the many highly trained welding experts who design and produce BURDOX products for every welding and cutting process—men whose vast experience and superior "know-how" adds that extra "something" to every BURDOX product. These men work toward the traditional BURDOX goal: *find a way to do it better, faster, cheaper, easier.* So regardless of what your needs are—welding and cutting equipment, industrial gases or safety equipment—there is a BURDOX product that can take the guess-work and delay out of solving your *particular problem.* Don't just buy welding equipment—buy BURDOX and save man-hours *and* money. *If you do not have the Burdett catalog be sure to write for your free copy now.*

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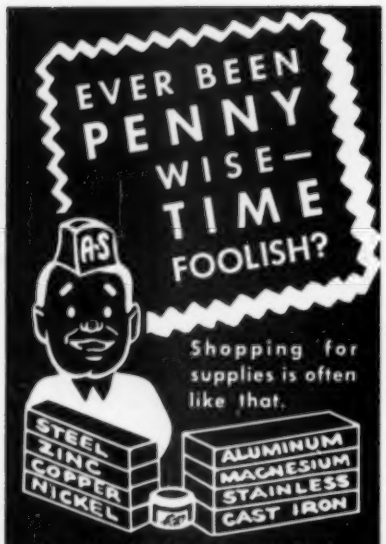

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1. ONE SOURCE OF SUPPLY

It makes sense to make your A-S Distributor and All-State your one proven source for all alloys and fluxes needed for welding, brazing, soldering, tinning and cutting.

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A-S Distributors stock a large variety of things you have to have quickly when you want them. They're competitive on price — usually lower if your eye is on the job costs. That comes of their handling All-State Alloys and Fluxes for all metals. They do better jobs for less.

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Each All-State Distributor has men especially qualified by training and experience to aid in the proper selection and use of alloys and fluxes for jobs where you might need help. Back of them, and always ready to pitch in on the problem jobs are the All-State regional men and the well-known All-State technical service facilities at White Plains, N. Y.

4. FREE LITERATURE

Ask for 32-page Buyers Guide to the complete line of All-State Alloys and Fluxes for welding, brazing, soldering, tinning and cutting.

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WELDING ALLOYS CO., INC.
White Plains, N. Y.

The new firm has offices in the Chrysler Bldg. at 405 Lexington Ave., New York. Evan A. Johnson, formerly with Hydrocarbon Research, Inc., is president of the organization.

South's First Welding-Electrode Plant

Westinghouse Electric Corp. will build an ultra-modern plant for the manufacture of welding electrodes and brazing alloys near Montevallo, 38 miles south of Birmingham, Ala., it was announced recently.

This will be the first welding electrode plant in the South. Its principal product—welding electrode—will supply all of the South and the Pacific Coast states, and the brazing alloys manufactured here will be shipped throughout the United States.

Plans call for a one-story steel and brick structure, running more than 400 ft along state route 25, and the most modern materials handling system available.

In addition to welding electrodes for normal industrial use, it will be equipped to produce some of the newest and latest types of electrodes that are being developed for armed forces' requirements.

Air Reduction Officially Opens Manufacturing Plant in New Jersey

The opening of the Union, N. J., plant of the Airco Equipment Manufacturing Division of Air Reduction Co., Inc., has been announced by Scott D. Baumer, president of the Division.

The new facility, employing approximately 1000 persons, has begun manufacture of welding and cutting torches, tips, regulators, oxygen and acetylene manufacturing and distribution equipment, gas-arc welding apparatus and oxy-acetylene cutting machines. The new plant houses the entire Airco Equipment Manufacturing Division.

The more than 12,000 different items produced by this division are sold domestically by various other Air Reduction divisions; in Canada by Air Reduction Canada Ltd; in Cuba by Cuban Air Products Corp. and internationally through Airco Co. International.

Physically, the plant is of brick and steel construction ,covering approximately 272,000 sq ft, on a 25-acre plot. The 18,000 sq ft of office space is completely air conditioned. The entire plant has fluorescent lighting.

The property is adjacent to the main line of the Lehigh Valley Railroad and within a mile of U. S. Route 22 and N. J. State Highway 29.

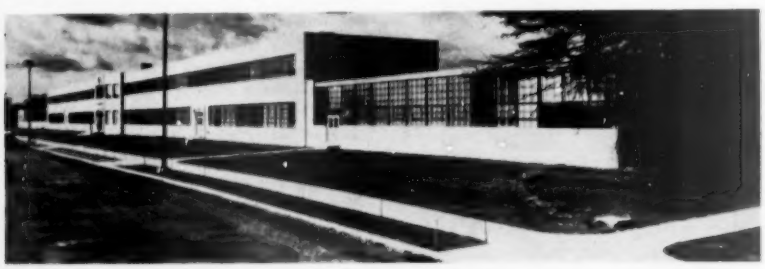
G-E Offers Free Decal for Welding Helmets

A new "Joe Magee" decal for welders' helmets is being offered free of charge by the General Electric Co.'s Welding Department, it was announced recently.

The two-color oval decal, measuring $1^1/_2$ by $2^1/_2$ in., portrays Joe's proficient welding technique and his ability to execute a flawless weld while laying on his back.

"Joe Magee," a cartoon character, was developed during the last war to illustrate proper welding technique in G-E training films.

The decal can be obtained from G-E welding distributors or by writing directly to the company at Schenectady 5, N. Y.



General View, Airco Equipment Manufacturing Division, Union, N. J.

Charleston Bulk Storage Facility

The Air Material Command has formally accepted the $2,341,000 petroleum bulk storage facility at N. Charleston, S. C., and placed it into operation. Constructed under the direction of the Charleston district of the U. S. Army, Corps of Engineers, this storage depot for airplane gasoline and jet fuel has a total capacity of 23,500,000 gal.

General American Transportation Corp., Chicago, furnished and erected seven steel storage tanks, each with a capacity of 80,000 bbl and fitted with Wiggins Hidek floating roofs for vapor conservation. General contractor for the entire project was Merritt-Chapmen & Scott Corp. of New York.

Tankers arriving from Gulf ports in the southern United States or from overseas, will pump their cargoes ashore through 12-in. flexible rubber hoses connected with reducers to twin 18-in. diam over and underground pipe lines. These pipe lines will carry the fuel 2½ miles to the Charleston Bulk Storage Facility. The overground pipe line is supported by concrete piers and timber piles.

Salt water will be pumped through the lines from dock side to purge them whenever there is a change in the type of fuel to be sent from the dock to the storage facility. This will be done by an electrically operated centrifugal pump connected to a 10-in. outboard pipe line at the dock. Upon arriving at the facility, the fuel will be boosted into the 80,000-bbl storage tanks by three electrically operated centrifugal pumps.

The seven all-welded tanks are 120 ft in diameter and 40 ft high. The Corps of Engineers selected Hidek floating roofs for these tanks because of excellent drainage characteristics, easy accessibility for inspection and maintenance, and effective seal for retention of volatile fractions. As is customary, the tanks and floating roofs will not be painted until the steel has weathered sufficiently to allow the mill scale to peel off.

All fuel arriving at the storage depot will be filtered before going through the booster pumps to the tanks. This will insure removal of any foreign solids which might damage the delicate valves in the pumps.

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Carbide
IN THE RED DRUM
EFFICIENT
ECONOMICAL
DEPENDABLE

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Use National Carbide in the Red Drum
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60 E. 42nd St. NATIONAL CARBIDE COMPANY New York 17, N.Y.
A Division of Air Reduction Co., Inc.

abstracts of
CURRENT WELDING PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25c from the Commissioner of Patents, Washington, D. C.

2,618,321—"Air-Cooled Gas Heating Torch"—George R. Spies, Jr., Berkley Heights, N. J., assignor to Air Reduction Co., Inc., a corporation of New York.

The patented gas heating torch comprises a head with a plurality of tips secured to and projecting from the head, and means are furnished for delivering heating gases to the head. The head has passages for conducting the heating gases to the tips, and a heat-dissipating shield is secured to the head and has a bottom portion provided with tip-receiving openings into which the ends of the torch tips project. Heat-dissipating fins are also provided in a portion of the heat-dissipating shield.

2,618,322—"Flashback-Proof Gas Burner"—Lewis D. Conta, Rochester, N. Y., and John Teti, Plainfield, N. J., assignors to Air Reduction Co., Inc., a corporation of New York.

In this patent, an antiflashback multiflame gas burner is provided and such burner includes a burner block with special passageways and slots provided therein for preventing flashback in the burner.

2,618,325—"Method of Controlling a Burner Flame"—Rudolph O. Seitz, East Orange, N. J., assignor to Air Reduction Co., Inc., a corporation of New York.

This patented flame control method includes the steps of feeding premixed gases including a fuel gas to a series of discharge orifices arranged in a small circle and discharging the gas mixture from the discharge orifices to form a plurality of separate jets of the gas mixture which surround a central axis with which the circle is concentric. The velocity of the jets of gas mixture and the dilution of the gas mixture in the jets by the surrounding air will be such that the rate of burning of the diluted gas mixture when ignited will substantially equal the velocity of the jets of gas mixture and the gas mixture and the jets will burn to produce a single flame the base of which remains substantially at a predetermined point along the central axis of the burner.

2,618,725—"Can Key Welding Machine"—Roland E. Renard, Los Gatos, Calif., assignor to Pacific Can Co., San Francisco, Calif., a corporation of Nevada.

Renard's patent is on a special apparatus including electrodes and positioning means by which a can-opening key can be welded to the can end which is coated with dielectric material on its inner and outer surfaces and has a bare peripheral edge.

2,618,726—"Method and Means for Securing Metal Members Together"—Robert R. Cameron, Denver, Colo.

The new welding method of this patent relates to a method for securing two metal bars in end-abutting relation. The method comprises placing a relatively thin metallic link between the abutted extremities of the bars and connecting the link to an electrical source. The applied current fuses the link between the bars and the portion of the link between the bars is reduced in cross section to create an area of maximum electrical resistance between the abutting bars.

2,618,727—"Automatic Welding Machine"—Horace Adrian Osborne, Frankfort Township, Will County, Ill., assignor to Morton Manufacturing Co., Muskegon Heights, Mich., a corporation of Michigan.

This patent relates to a machine for the automatic fusing of the upper edge of a vertical flange and it includes a head which is supported for universal movement in a horizontal plane. A pilot member is fixed to the head and contacts an inner surface of the flange to be fused while a driving member is connected to the head and contacts an outer surface of the flange. Other locating and guide means are provided in the machine to position the guide accurately relative to the flange during relative movement therebetween.

2,618,775—"Remote Control Electric Arc Welder"—Albert R. Shay, Mantua, Ohio.

Shay's patented system relates to apparatus including an engine-driven generator, a battery charging generator, a reverse current cut-out for the battery charging generator, and a reversing switch in circuit with the generators for reversing the polarity of the engine-driven generator. A rheostat is provided in series with the field of the excitor provided for the engine-driven generator, while a shunt is connected to the first generator and has a second rheostat electrically connected to such shunt. The second rheostat has an off position and is electrically connected to the reversing switch so that the driven generator is controlled by the rheostat for the starting and stopping thereof and that, as such action occurs, the switch will be operated to change the polarity of the driven generator.

2,618,781—"Welder's Protection Means"—Andre R. Beauverger, Beziers France.

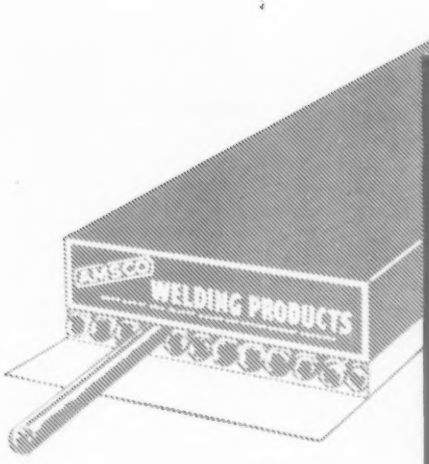
This patent relates to a welder's opaque protection mask which has two window openings. A translucent solid sheet member is mounted in one window opening and a transparent solid sheet member is positioned in the other window opening with the two sheet members being placed in the mask to form an acute angle of which the vertex is outwardly directed from the mask. A rotatable screen is pivoted on the mask outside of the vertex and means are provided for setting the screen in at least two positions with relation to the mask window openings.

2,618,839—"Apparatus for Welding Double Tabs to Cathode Sleeves"—Leon C. Morrell, Bloomfield, N. J., assignor to Radio Corporation of America, a corporation of Delaware.

Morell's patent is on special apparatus for welding a ribbon connector to one end of a cathode sleeve and for bending a portion of the connector to form a double tab extending from the end of the sleeve as the sleeve is removed from the supporting means provided in the apparatus.

2,619,591—"Low-Frequency Welding Control"—John R. Parsons, Kenmore, N. Y., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

This welding control relates to the combination of four electronic discharge devices which are connected in circuit with each other and with timing circuits so that the various electrical discharge devices and their associated circuits are rendered conductive in predetermined relationship to each other.



How AMSCOATING with Amsco Hardfacing Rods saves you materials . . . manpower . . . money.

Amscoating these guide shoes kicks tube production up

AMSCOATING . . . stands for control of wear by Hardfacing . . .

Hardfacing Rods—and recommendations for their use—are as sound as the manufacturer who makes them. AMSCO has been fighting wear for a half-century—first with Manganese Steel, and later with AMSCO Hardfacing Products.

If you have a problem of wear caused by impact, abrasion, heat or corrosion . . .

Find out how AMSCOATING can save you materials . . . manpower . . . money!

Continuous production, greater safety and better weldability are three good reasons for Amscoating Piercer Guide Shoes.

These Piercer Guide Shoes are used at a large midwestern steel plant to hold a rotating hot bar in alignment during the initial piercing operation. Wear was not the main problem here. The condition to be avoided was "pick-up", where the bar becomes fused with shoe and literally explodes.

To lick this problem, which can result in expensive equipment damage and loss of life, the welding superintendent chose Amsco Thermalloy No. 4 for three reasons:

1. **Complete elimination of pick-ups . . . for greater safety and higher production**
2. **Better weldability . . . Thermalloy No. 4 covers heat checks, prevents small cracks that can cause pick-ups or seizing.**
3. **Amscoated shoes can be used many times . . . for big savings in replacement costs over a year's period.**

AMSCOATING permits big savings—through longer service and fewer replacements—on many other applications. If you have equipment that's subject to wear, the possible savings to you—are too big to be overlooked!

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Brake Shoe COMPANY

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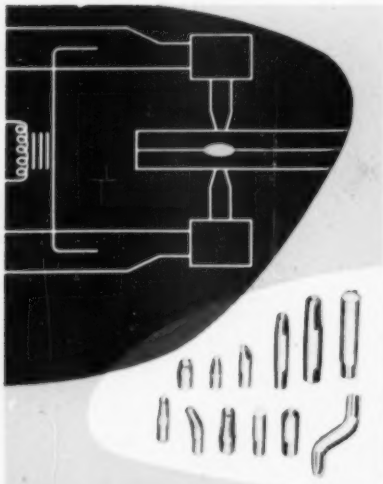
Other Plants: New Castle, Del., Denver, Oakland, Cal., Los Angeles, St. Louis. In Canada: Joliette Steel Division, Joliette, Que.
Amsco Welding Products distributed in Canada by Canadian Liquid Air Co., Ltd.



Good tips
for resistance-welding machine users

AMPCO WELD*

spot-welding tips
cut costs, downtime;
increase production

Ampco Weld spot-welding tips can take it. Manufactured under rigid laboratory control at Ampco's own plants, they resist mushrooming and wear and their high electrical conductivity minimizes sticking to the work.

This outstanding combination of properties results in a resistance-welding electrode that requires fewer dressings and pays off in longer runs, reduced downtime, lower costs.

Ampco Weld tips are only part of a complete line of resistance-welding products, not only meeting but exceeding RWMA specifications. Ampco Metal, Inc. gladly furnishes engineering service for special applications. Step up your production — order Ampco Weld resistance-welding tips now.

*Reg. U. S. Pat. Off., Ampco Metal, Inc.

AMPCO Ampco Metal, Inc.
Milwaukee 46, Wisconsin
West Coast Plant: Burbank, California
It's production-wise to Ampco-ize!
RW-5

2,619,707—"Automatic Indexing Drill Press and Flame Cutting Machine"—Leo L. Young, Albert C. Drechsler, and Bronislaw T. Brzozowski, Cleveland, Ohio, assignors to General Motors Corp., Detroit, Mich., a corporation of Delaware.

In this flame cutting machine, a template is provided having openings therein and suitable template tracer mechanism is connected in the machine and has a cutting torch supported on the machine and controlled by the tracer mechanism. A drilling mechanism is also provided on the frame and a template ramp is movable into the template opening and engagable by a tracer roller provided for positioning the cutting tip in alignment with holes drilled by the workpiece drilling mechanism, to start the cutting operation by the torch.

2,619,928—"Appliance for Use in Welding"—Ernest P. Pierce, Cleveland, Ohio, assignor to John R. Milburn, Cleveland, Ohio.

In this welding appliance, a stationary frame is provided with two work holders each of which has driven means and is pivotally mounted upon the frame so that their individual driven means are movable into and out of operative engagement with a drive shaft. A unitary control lever is provided for both work holders to control the position of such members and move one work holder into operative position while moving the other into inoperative position.

2,620,420—"Welding Machine"—John H. Abbott, South Gate, Calif., assignor to Utility Appliance Corp., Los Angeles, Calif., a corporation of California.

Abbott's patent relates to a frame having an operating station, and retaining means carried by the frame for holding a tubular workpiece. The retaining means are rotatable about the axis of the tubular workpiece to move successive portions of the workpiece to the operating station. Other means are provided in the apparatus for reinforcing the tubular workpiece as various operations, such as welding, are performed thereon.

2,620,421—"Roof Welding Machine"—Stephen J. Matosec, Hammond, Ind., assignor to Pullman-Standard Car Manufacturing Co., Chicago, Ill., a corporation of Delaware.

A production welding apparatus for railway box car roofs is disclosed in this patent. The apparatus includes a rigid fixed base frame structure having logitudinally extending rails, and a roof assembly fixture is carried by the base frame structure. A welding machine is movable longitudinally on the rails and has various special means associated therewith for performing a welding operation on sheets carried by the roof assembly fixture.

2,620,422—"Arc Welding Apparatus"—Charles Volff, Montreal, Quebec, Canada, assignor to L'Air Liquide, Societe Anonyme pour l'Etude et l'Exploitation des Procedes Georges Claude, Paris, France.

This novel arc-welding apparatus includes an electrode connected to a welding current source, the other pole of which is connected by an insulating piece and an electrically conducting ring surrounds the exterior of the insulating piece with the electrode and the workpiece having direct connections to the poles of a high-frequency generator. An indirect connection only is provided between the ring and the pole of the high frequency generator which is connected to the workpiece. The indirect connection includes a capacitor, and the distance between the electrode and the ring in respect to the high-frequency potential is sufficiently high to produce a luminous discharge around the electrode.

2,620,423—"Method of Electric Welding"—Max Komers, Muelheim-on-the-Ruhr, and Hermann Potzl, Munich, Germany.

This patent relates to a method of submerged arc welding wherein relative movement is provided between two spaced-apart electrodes and two steel pieces having large cross sections. Fused electrode metal is deposited from the leading electrode and a major portion of such deposited metal is permitted to become solidified after which fused metal from the following electrode is deposited on the solidified fused metal from the leading electrode by melting the following electrode in the liquid slag and the liquid residual melt of the preceding electrode, if any. The spacing between the electrodes is correlated so that the previously deposited layer of welded metal substantially remains solidified.

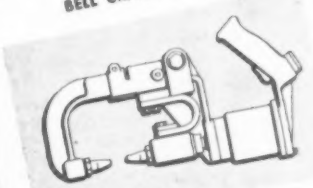
2,620,424—"Method of Resistance Welding Tantalum"—George Otto, Gurnee, Ill., assignor to Fansteel Metallurgical Corp., North Chicago, Ill., a corporation of New York.

This resistance welding method relates to the production of a composite metallic body of at least two metal elements one of which is composed of tantalum. The welding method includes the steps of interposing a thin film of carbon between the welding electrodes and the metallic elements, and passing an electrical welding current through the electrodes, carbon film and metallic elements. The welding electrodes are composed of metal having a lower melting point than that of tantalum.

2,621,278—"Electric Arc Welding"—Albert Muller, Plainfield, N. J., assignor to Air Reduction Co., Inc., a corporation of New York.

SCISSORS ACTION

BELL CRANK ACTION



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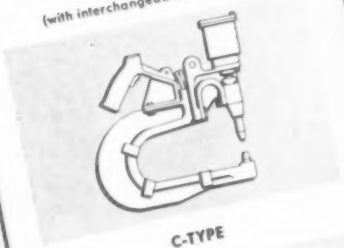
(with interchangeable adapters)



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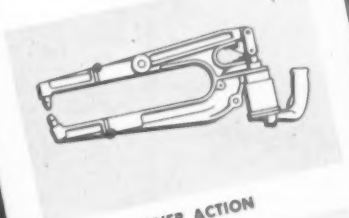

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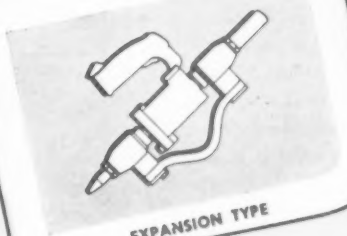

EXPANSION TYPE

Illustrated Link Guns are only a few of the many designs available for light and heavy duty welding.

LINK Portable Guns are designed for efficiency in high resistance welding production. Proper cable capacity, correct counterbalancers for gun weights, proper electrical controls and many other time, effort and cost saving factors have been given pointed consideration in the design and engineering of this equipment.

All Link Portable Gun Units may be equipped with hydraulic boosters to give up to 2,000 lbs. point pressure.

Above: Link Dual Gun Unit which can combine two or more guns with different weld times.

LINK
PORTABLE GUN UNITS
designed to meet every spot welding requirement efficiently, economically!

Submit your welding problems to Link Welder for complete, competent analysis and recommendations. No obligation. Write today.

LINK

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LINK WELDER CORPORATION

Designers and Manufacturers of High Production Welding Equipment

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WELDING CURTAINS

Workers and passers-by are protected from harmful rays given off by welding operations. Also serve as a protective shield against flying chips and scale. Made of special flameproof and waterproof canvas — or asbestos — complete with eyelets for suspending on rod or pipe support.

WRITE FOR BULLETIN A-43

IPCO *Safety Equipment for all Industries*

INDUSTRIAL PRODUCTS COMPANY

2832 N. FOURTH ST., PHILADELPHIA 33, PA.

This patent relates to a method of welding a ferrous metal such as rimmed or semikilled steel containing substantial amounts of oxygen and carbon. The welding method comprises fusing a portion of the ferrous metal with an electric arc to form a weld pool of molten metal, feeding into the weld pool a bare ferrous wire, and consuming the end of the filler wire, which wire end and weld pool are blanketed with a stream of inert monatomic shielding gas to exclude air from the molten metal and prevent loss of the deoxidizer. A special composition wire is used in this welding operation.

2,621,399—"Process for Welding Seams in the Manufacture of Lift-Type Gas Holders"—Arthur C. Thompson, Baltimore, Md., assignor to Koppers Co., Inc., Pittsburgh, Pa., a corporation of Delaware.

Thompson's patent relates to a process for constructing a metal vessel which has a series of panels which are bolted together and have outwardly opening crevices at the bolted joints through which air can escape when the internal air pressure in the vessel is greater than atmospheric. The method includes forcing a combustible caulking material into the outwardly opening crevices and then welding the caulked joints. The caulk material is impregnated with a fire-retardant whereby it burns out slowly without substantial flame under the intense heat of the welding action.

2,621,717—"Annular Torch Head for Flame Hardening Machines"—David M. Strauchen and Milton Garvin, Cincinnati, Ohio, assignors to The Cincinnati Milling Machine Co., Cincinnati, Ohio, a corporation of Ohio.

The patented torch head for a heat-treating machine includes a discontinuous annular housing providing a radial opening in the periphery thereof through which temperature measurements can be made of work being heated within the surrounding housing. The housing includes a cylindrical perforated baffle plate and a perforated burner plate which is removable positioned in the apparatus so that interchangeable burner plates having different perforation patterns therein may be used in the apparatus. Such perforations form the burner ports in the apparatus.

2,622,179—"Electric-Arc Welding Apparatus"—Trevor Lumsden Herbert Butterfield, Guilford, England, assignor to Bowler & Sidney, Ltd., Slough, England, a British company.

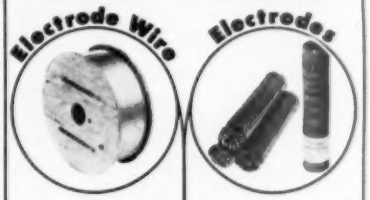
This patented arc-welding tool is for welding studs and similar small articles to workpieces and it includes a frame body with a stud chuck spindle positioned thereon. Special means are provided for controlling the movement of the stud chuck spindle during fusion of the stud adjacent to the workpiece and feeding it slowly at such time until formation of a molten crater in the workpiece and then permitting rapid movement of the stud chuck spindle to drive the stud into the molten crater. Movement of the spindle is initiated by flow of welding current.

Bound Volume 1952

Bound volume of The Welding Journal for the year 1952 is available in black imitation leather cover, together with a comprehensive subject and authors index. Price $15. This volume, comprising a total of 1200 pages in the Journal and an additional 624 pages in the Welding Research Supplement, represents a veritable encyclopedia of information in the welding field. Copies may be ordered through the American Welding Society, 33 W. 39th St., New York 18, N. Y.

Weldwire Company Inc.

WELDSPOOL **WELDBEST**



	INERT GAS WELDING	MANUAL ARC WELDING
ALUMINUM		
	Weldspool 43S	Weldbest 43S
	Weldspool 2S	Weldbest 2S
	Weldspool 52S	Weldbest 52S
TITANIUM		
	Weldspool 930	
STAINLESS		
	Weldspool 304 ELC	Weldbest 307
	Weldspool 308	Weldbest 308
	Weldspool 309	Weldbest 309
	Weldspool 309 Cb	Weldbest 310
	Weldspool 310	Weldbest 316
	Weldspool 316	Weldbest 330
	Weldspool 321	Weldbest 347
	Weldspool 347	Weldbest 349
	Weldspool 349	
STRAIGHT CHROMIUM STEELS		
	Weldspool 405	Weldbest 410
	Weldspool 410	Weldbest 430
	Weldspool 420	Weldbest 442
	Weldspool 430	Weldbest 446
		Weldbest 501
		Weldbest 502
LOW ALLOY STEELS		
	Weldspool 70000	Weldbest 90
	Weldspool 90000	Weldbest 100
	Weldspool 120000	Weldbest 230
		Weldbest 260
HARD SURFACING		
		Weldbest 139 (14% Mn)
NON FERROUS ALLOYS		
	Weldspool 600-Cu	Weldbest 610 SiBr
	Weldspool 610-SiBr	Weldbest 620C PBr
	Weldspool 620-PBr	Weldbest 730 CuNi
	Weldspool 630-AlBr	Weldbest 760 Cast Iron
	Weldspool 730-CuNi	Weldbest 770 Monel
	Weldspool 770 Monel	Weldbest 780 Niconel
	Weldspool 780 Niconel	Weldbest 790 Nickel
	Weldspool 790 Nickel	

ELECTRODE WIRE: Chemically Processed-Precision Spooled
ELECTRODES: Lime DC—Titania AC-DC—LIME AC-DC

ALSO MANUFACTURERS OF:
WELDWIRE: GAS WELDING RODS
WELDBEST ARC OXYGEN CUTTING RODS
WELDBEST: UNDERWATER ARC OXYGEN RODS
WELDBEST: ARC OXYGEN ¡ELECTRODE HOLDER AND
WELDBEST DEEPWELD: DEEP PENETRATING CARBON STEEL ELECTRODE

Send for Technical Literature

WELDWIRE COMPANY, INC.

N. W. Cor. Emerald & Hagert Sts.
Philadelphia 25, Pa.
Phone: Garfield 3-1232

NEW PRODUCTS

Phosphor Bronze Electrode

An improved phosphor bronze electrode announced by All-State Welding Alloys Co., Inc., White Plains, N. Y., has some unusually attractive features for arc brazing nickel alloys and cast and malleable iron; and for arc welding copper, bronze and brass.

Analysis of arc deposit shows: Copper 91.73%, tin 7.85%, silicon 0.07%, phosphorus 0.05%, iron 0.20% and other 0.10%. Mechanical properties are substantially superior to those characterizing standard grades. Comparison indicates tensile strength is 61,000 vs. 52,000 psi, yield is 34,000 vs. 33,000 psi, elongation in 2 in. is 42.5% vs. 24%, Brinell hardness is 72 vs. 78.

The product is All-State No. 24 Type "C" Phosphor Bronze Electrode. A special flux is said to completely encircle each drop of metal as it leaves the electrode and to provide "globular protection" until it reaches the base metal and is deposited. This assures maintenance in the deposit even of the tin in the original analysis. It also enables complete "floating out" of slag or impurities in a form which is easily removable. Deposition rate is high at all current settings, with minimum of splatter and maximum appearance and physical properties. Reverse polarity d-c current only is used.

All-State No. 24 is available in six standard sizes from 3/32 in. up to and including 1/4 in. Supplies are available from some 650 All-State distributors throughout the country.

New "Paint-On" Solder Paste-Flux Combination

A new paint-on solder paste combined with flux, trade-named "Eutec-TinWeld," claimed to vastly increase speed of application while cutting waste to a minimum, has been released by Eutectic Welding Alloys Corp., Flushing, N. Y.

The new product, which can also be used as a tinning compound in paste form for all tinning operations, is reported to be ideal for production and repair items and for intricate parts where conventional methods are impractical.

Basically, "TinWeld" consists of a specially formulated lead-tin-solder that is pre-mixed, in paste form, in proper proportions with its specially compounded accompanying flux. The resultant product is said to yield a capillary flow similar to silver solder with strengths equivalent to conventional lead-tin solders, while completely eliminating the waste and awkwardness involved in melting solder off a stick or coil in the ordinary way.

Whatever small amount of flux residue may result from the "TinWeld" paste application can swiftly and easily be washed off with plain water, thereby easily preventing corrosion, the manufacturer reports.

Since this new formulation permits brush, spatula or dip application, it is said to be ideal for work where preplacement of alloy is required for furnace, automatic soldering, and similar operations; for tinning on auto body work; for tinning of odd-shaped parts normally difficult to reach with a solder in wire form; for delicate work requiring small amounts of alloys, such as jewelry, etc., since parts to be joined may be dipped *into* "TinWeld" paste.

New "TinWeld" can be used with torch, furnace or soldering iron to join all metals except aluminum and magnesium. No additional or outside flux is ever required.

Prices and additional information on this new product may be obtained by writing the manufacturers: Eutectic Welding Alloys Corp., Dept. P, 172nd St. and Northern Blvd., Flushing 58, N. Y.

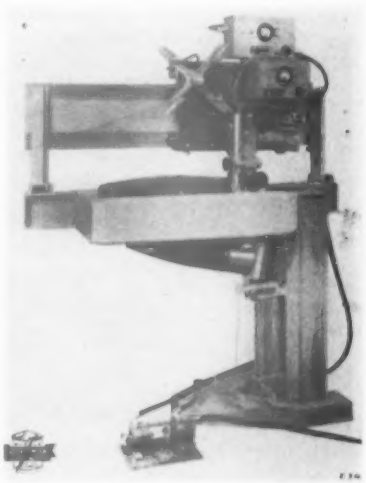
Aluminum Bronze

Aluminum bronze-coated electrodes depositing weld metal with Brinell hardnesses of 100 and 250 available. Also spooled aluminum bronze wire for gas-shielded metal-arc welding. Data sheets on request. Weldwire Co., Inc., Philadelphia 25, Pa.

Heliarc Jig

Manufacturers of bombs, airplane and guided missile components, tanks, fire extinguishers and tubing, of many types and shapes, are discovering the extreme usefulness and versatility of the Heliarc Welding Jig now in full production by the McHale Manufacturing Co. of Los Angeles.

Developed and thoroughly tested within the past 2 1/2 years for the stainless steel dairy equipment field and in many industrial processes, the inert-arc machine has recently been successfully pressed into service in manufacturing of war production items where stronger, smoother welding results with less grinding and finishing are so necessary.



The McHale Heliarc Machine consists of a pneumatic work-clamping jig, a power-operated welding head carriage and Heliarc welding equipment in which a tungsten electrode operates in an accurately timed atmosphere of inert gas. The carriage on the jig is adjustable for a welding speed of 4 to 60 rpm on its horizontal track. Bomb, airplane, guided missile and component parts manufacturers find the jig's end opening or gap feature very practical because it permits welding of all longitudinal seams of any formed item, with easy removal of resulting shape.

There is provision also for conversion to Heliarc spotwelding—a method which can consistently produce a weld capable of withstanding 300 to 900 lb of pressure per square inch. The jig accommodates stock ranging from 28 gage sheets to 1/2-in. plates and is adjustable on pressure from 5 to 60 lb, depending upon the material welded.

For further information apply to Lloyd Johnson, McHale Manufacturing Co., 3200–3220 E. Mines Ave., Los Angeles 23, Calif.

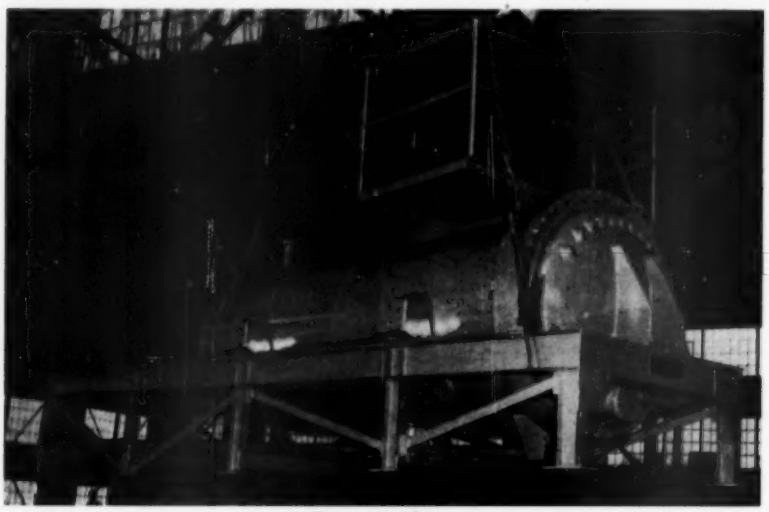
Plastic Cover Lens

Welcast Plastics Co., 721 E. Baird Ave., Barberton, Ohio, has developed "Welcast" CR 39 welding plastic cover lens. The

demand for these plastic lenses is due to their increased useful life under all types of welding as compared to all other lenses. A useful life of 50 times that of ordinary lenses is not uncommon. These "Welcast" lenses are packaged in individual envelopes.

Pressure Filters

Twenty-four retractable shell type pressure filters, for use in a new basic aluminum plant, were fabricated recently at the Pittsburgh plant of Dravo Corp. Developed by the H. W. North Co., Erie, Pa., filters of this design are reported to have a wide range of application for pressure filtration in the chemical, metallurgical and allied industries. Entirely of welded steel construction, the filter shell is 14 ft long by 60 in. in diameter. It is mounted horizontally in a steel framework and rides on roller bearing wheels, being retracted by a screw traversing mechanism. Full exposure of the filter leaves without disconnecting piping enables the operator to service the equipment quickly and conveniently. Head of the unit is stationary and is breech-locked to the shell by remote control.



Pressure filters

Flame-Resistant Curtains

Impregnated, flame-resistant canvas curtains and blankets that can be hung to form inexpensive booths to screen off dangerous operations are now being offered by Eastern Equipment Co., Inc., Willow Grove, Pa. The curtains and blankets afford complete protection for workers near arc welding and other operations where arc flash, molten splash, flying chips, scale, etc., are produced. Curtains are made to individual requirements from 8-, 10- or 12-oz duck and from Underwriters' grade asbestos cloth in sizes to over 100 sq ft. They contain sturdy, firmly fastened brass grommets a foot apart on one long side. All edges are hemmed and seams are double-row stitched for added strength. The blankets are made with

grommets in each of the four corners. Additional grommets can be furnished where required on either the curtains or blankets.

For additional information, write Eastern Equipment Co., Inc., Willow Grove, Pa.

Flame Machine Cutter

A new 3-spindle flame cutter for producing gears and sprockets has been announced by Cogmatic Co., Milwaukee, Wis. In addition to the advantage of cutting alloy steel as quickly as mild steel, and hardening while cutting with coolant stream, a number of new production advantages are claimed. Jury spindle attachment (see photo) makes it possible to produce sprockets or gears that are actually bigger than the machine itself. Multiple spindle design, also new, permits automatic production of three gears or sprockets at a time, in diameters up to 15 in.; two at a time up to 25 in. diameter.

The Cogmatic unit is said to be capable of machining as much tooth metal per hour as is possible with three conventional gear-cutting machines. It automatically produces over 300 shapes and sizes of teeth, 5 to 200 teeth per wheel, diameters 3 to 108 in. Because it can turn out these many shapes and sizes from plate steel,

Buy "PROVEN FLUXES"

Years of GUARANTEED SATISFACTION

behind these GOOD

"ANTI-BORAX" FLUXES

Insist on them — Unequalled Quality

No. 1 Cast Iron Welding Flux
No. 2 Brazing Flux for Brass, Bronze, Steel, etc.
No. 4 Brez-Cast Flux for Bronze Welding Cast Iron
No. 5 & 8 Cast & Sheet Aluminum Fluxes
No. 9 Stainless Steel Welding Flux
No. 11 Tinning Compound
No. 16 Silver Solder Paste Flux

Mfg. By

ANTI-BORAX COMPOUND CO., INC.

Fort Wayne, Ind.

WELDING CONNECTORS

Saxe Welding Connection Units position and secure structural parts to be welded.

Clip K3A permits an adjustable connection.

These widely used units eliminate all hole punching, and, with welding, produce the most economical, safe, and quickly erected structural frame.

Write for 1951 edition, Structural Welding Practice Manual.

J. H. WILLIAMS & CO.

Buffalo 7, N. Y.

AIR REDUCTION CANADA, LTD.

Montreal 2, Canada

Simplified Precision Welder Control

for easier maintenance and increased dependability

Class 8993 NEMA Type S2H Synchronous-Precision Controller available with 600 or 1200 frame contactor. Can be arranged either for side of machine or wall mounting.

DESIGN LEADERSHIP

APPLICATION: *for welding stainless steel, nonferrous metals, and other critical spot welding jobs requiring electronic synchronous-precision control. (Available with current wave shape control auxiliaries for aluminum or alloy metals.)*

DESIGN LEADERSHIP features

Easier Maintenance . . . greatly simplified circuits require fewer tubes and only one operating relay (for the air valve).

Increased Dependability . . . all components designed specifically for industrial welder service. Tube circuits are fail-safe and initiating contacts are in isolated 24 volt circuit which supplies power to the valve relay.

Consistent Accuracy . . . regulated DC voltage on tube control grids compensates for supply fluctuation or tube variations . . . assures timing accuracy.

Greater Accessibility . . . timer, heat control and firing panels designed for easy inspection and maintenance, with quick fasteners and plug connectors.

Write for BULLETIN 8993
or consult your nearby Square D Field Engineer

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WITH the new Brush Welding Analyzer you can instantly spot improper calibration or inconsistent or faulty operation of three-phase resistance welders, single-phase resistance spot, projection, and seam welding machines. Chart records, which are immediately available, show the magnitude and timing of all welding variables, and indicate faulty firing of ignitron tubes or other difficulties.

In addition, the Brush Analyzer helps you make sure you meet specifications. Side by side on the chart are the two records of welding current and electrode force . . . showing contact gage settings, precompression force, weld force, rate of rise, forge force, and time of operation in milliseconds.

Brush Analyzers save you time in welding analysis, and in studies of AC or DC voltage or currents, strains, displacements, stresses, and other static or dynamic conditions. Brush representatives are located throughout the U.S., in Canada: A.C.Wickman Ltd., Toronto. For bulletin write Brush Electronics Company, Dept. JJ-2, 3405 Perkins Avenue, Cleveland 14, Ohio.

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inventory requirements are minimum. The Cogmatic machine is available to manufacturers who incorporate gears and sprockets on their products, as well as to flame-cutting and welding shops who want to expand by manufacturing gears and sprockets for industry. More information can be had by writing to Cogmatic Co., 1330 N. Franklin Place, Milwaukee, Wis.

All-Plastic Welding Helmets

American Optical Co. announces an entirely new line of one-piece compression molded plastic welding helmets. The new No. 700 Series helmet shell is made of thermosetting Fiberglas reinforced with polyester resin. It possesses many advantages over materials generally used in welding helmets.

Its seamless construction makes this helmet exceptionally strong and the Fiberglas material is moistureproof and resistant to high heat. It will not warp and is lighter than vulcanized fiber. Tests indicate superior wear and performance. It has a perfectly smooth surface which can be easily cleaned or sterilized.

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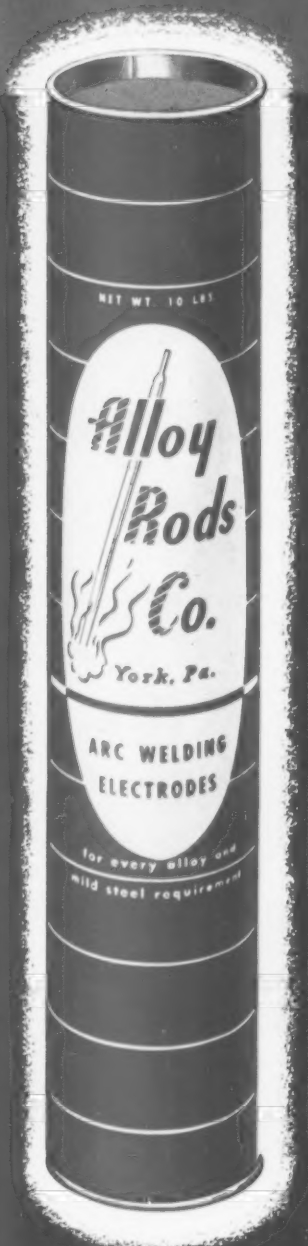
Welders everywhere will tell you there are NO FINER ELECTRODES MADE...ANYWHERE!

ARCALOY stainless steel electrodes for every stainless steel welding requirement. Lime coating for all-position welding, reverse polarity. AC-DC coating for chrome-nickel steels with all types of AC or DC welding equipment. Twenty-three regular analyses, plus several special analyses. *Write for Bulletin 5751.*

BRONZE-ARC phosphor bronze electrodes for all-position welding with reverse polarity on DC. Smooth, easy-flowing arc eliminates any erratic arc action. Makes superior low-spatter, dense, porosity-free, high-strength welds on bronze, brass, copper . . . excellent to join dissimilar metals. *Write for Bulletin AR53-1.*

NICKEL-ARC, NICKEL-ARC 60 electrodes for cast iron. Nickel-Arc 60 is the finest electrode available today for cast iron welding. Like the well-known Nickel-Arc, it has a smooth arc and spatter-free action with AC or DC. Soft machinable deposit is ideal for repairing broken or worn castings. *Write for Bulletin 2218.*



AR-11

Packaged in the familiar Alloy Rods red and yellow all-metal moisture-proof containers, every rod reaches you in "oven fresh" condition.

TOOL-ARC electrodes for tools and dies weld each of the five basic types of tool and die steels including: oil hardening, hot work, water hardening, high speed, and air hardening . . . also for work hardening applications. Conserves material, saves man hours, and minimizes production delays. *Write for Bulletin AR52-1.*

WEAR-ARC hard-facing electrodes for fast, economical, efficient rebuilding and hard-facing to resist abrasion, impact, compression, corrosion, and heat. Nine basic types for correcting specific wear patterns, reclaiming worn equipment and parts, guarding against future wear. *Write for Bulletin 5651.*

WELD-ARC low hydrogen electrodes for welding high carbon, high sulphur, free machining, and other difficult-to-weld steels, with AC or DC. Low spatter loss, high deposition efficiency, very quiet arc action, free from tendency to undercut, welds free from under-bead cracking. *Write for Bulletin AR51-1.*

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"Delivers pressures that do not vary as the cylinder empties . . ."
"Most accurate regulator I have ever used regardless of price . . ."
"Gives steady gas-flow for hour-after-hour welding . . ."
"Plenty of volume for heavy-duty cutting right down to the end of the cylinder . . ."
"One setting is enough to do any job . . . and readjustments are never necessary . . ."
"Not just good performance . . . but rugged construction and easy maintenance, too . . ."
TORCHWELD

Here's why Torchweld "6500" delivers constant pressure and volume regardless of cylinder pressure

In any regulator the pressure of the incoming gas is one of the forces operating the valve mechanism. As cylinder pressure drops, this force decreases, causing a variation in the volume of gas flowing through the valve.

In the TORCHWELD "6500", a pressure compensating chamber below the seat counteracts the effect of this decreasing force.

A small passage in the valve seat permits gas at *cylinder pressure* to enter the chamber. At the bottom of the chamber is a reinforced rubber sealing disk. Below the disk is a pin which rests against the back of the regulator.

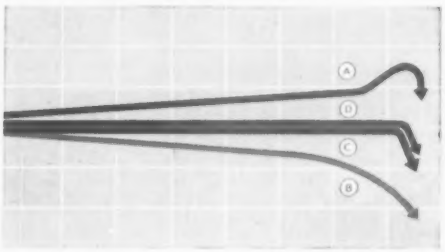
The forces within the chamber act upon the disk and pin so that there is a resultant effective force which tends to move the seat upward toward the nozzle.

As cylinder pressure drops this upward force diminishes, resulting in a gradual increase of the spacing between seat and nozzle. This compensates for the effects of decreasing cylinder pressures, and thus maintains constant delivery pressure and volume.

as truly revolutionary!

REGULATOR with pressure compensating chamber

Here's how various types of regulators act as cylinder pressure drops



Ⓐ *Stem-type* single-stage regulator delivers at *increasingly higher* pressures as the cylinder empties. Frequent pressure adjustments are necessary.

Ⓑ *Nozzle-type* single-stage regulator delivers gas at pressures that *drop lower and lower* as the cylinder empties. Frequent pressure adjustments are necessary.

Ⓒ *Two-Stage* regulator gives uniform working pressure regardless of cylinder pressure, depending upon quality of regulator. Pressure adjustments are avoided.

Ⓓ TORCHWELD "6500" REGULATOR delivers constant working pressure (whatever it's set for) regardless of drop in cylinder pressure. No adjustments are necessary to maintain desired flame characteristics.

Plants and welding shops everywhere are buying the TORCHWELD "6500" to get the best performance at the least cost

It costs only slightly more than the average single-stage regulator, but it gives the precise control heretofore available only in higher-priced two-stage regulators. That's the reason the TORCHWELD "6500" is the wise choice wherever regulators must be replaced, or new equipment ordered.

Acclaimed the first major advance in regulator design in 20 years, the TORCHWELD "6500" is a brand new *type* of regulator, combining the advantages of both single and two-stage regulation without the disadvantages of either.

The TORCHWELD "6500" delivers precise and constant working pressure (at whatever setting you choose) *regardless of decreasing cylinder pressure*. This is made possible, at a price to please every pocketbook, by the unique NCG-engineered "*pressure compensating chamber*"—an exclusive feature.

What's more—the "6500" has all the quality refinements characteristic of TORCHWELD—extra-big streamlined gas passages, exclusive "SPIREX" nozzle element that prevents seat ignition, inlet filter, relief valve, rugged construction and few working parts to wear or repair. Better write *today* for Bulletin No. NTW-104 and get *all* the details.

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SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Tooling for Automatic Welding

Bethlehem, Pa.—"Tooling for Automatic Arc Welding" was the subject of an extemporaneous talk given by Cecil C. Peck AWS of Cecil C. Peck Company before the December 1st dinner meeting of the *Lehigh Valley* Section held at the Hotel Bethlehem. Mr. Peck stressed the economy of automatic welding and brazing, particularly when used with well-designed jigs and fixtures. He stated that it was an essential to tool up for welding as for any other operation. His talk was illustrated with slides and was very interesting. During the question period which followed, Mr. Peck discussed some of the practical problems of automatic welding.

Coffee speaker was B. E. Service, General Manager of the Bethlehem Globe Times Publishing Co., who spoke on "Too Much for a Nickel." Mr. Service's talk was interesting and told of the problems of publishing a daily newspaper and also of a newspaper's policies and responsibilities.

Flame Stability

Boston, Mass.—The regular dinner meeting of the *Boston* Section was held on Monday evening, December 8th, at the Westinghouse Apparatus Warehouse and Auditorium. Sixty-five members and guests at dinner enjoyed the talk given by Captain Albert Chambers, USN retired, on "Some Anecdotes of the Sea."

Technical speaker was Professor James A. Browning, Thayer School of Engineering, Dartmouth College, Hanover, N. H., who gave an extemporaneous talk on "Welding and Cutting Flame Stability." This was a very interesting talk illustrated with blackboard diagrams and the use of some of the experimental equipment outlined in this article published in the October issue of THE WELDING JOURNAL. Professor Browning has done a great deal of research on flame stability for the government at the Thayer School of Engineering to better understand methods of controlling jet flames for jet aircraft. It is seen that the jet-engined plane or "flying blowtorch" is nothing more than a torch in the sky. The same basic principles control each and some of the new discoveries should have a profound effect on the flame-welding and cutting industry.

Effect of Cold Work

Buffalo, N. Y.—"The Effect of Fabrication on Steel Properties" was the subject of a talk by Dr. Robert D. Stout AWS of Lehigh University at a joint meeting of the *Niagara Frontier* Section of AWS and the Buffalo Chapter of ASM on December 4th. Dr. Stout described the results of laboratory tests designed to illustrate the effects of cold work, welding, cutting, and heat treating on a number of properties of mild steel, such as strength, ductility, notch toughness and fatigue strength in the plastic range.

Regarding strength, tensile prestrain raises the yield strength while compressive prestrain lowers the yield strength. Therefore, cold work must be uniform in order to strengthen steel.

Both cold work and welding reduce the ductility, but subcritical heat treatment considerably improves the ductility of welded plate, while cold-worked plate must be normalized to regain full ductility.

Both cold work and welding also adversely affect the notch toughness, but the effects are not additive when a cold-worked steel is welded. A relatively small amount of cold work lowers the notch toughness to about the same extent as a large amount, and the notch toughness may be restored by normalizing. Preheating and postheating tend to improve the notch toughness of weldments. The method used for edge preparation also affects the notch toughness. Of the three methods investigated, shearing was the most detrimental and machining the least, with flame cutting in between. Since the notch toughness could be considerably improved by normalizing, it appears that effect of edge preparation is primarily metallurgical.

Regarding fatigue strength in the plastic range, where the material is subjected to repeated stresses exceeding the elastic limit, welding is apparently detrimental at high strain levels but not at low strain levels. The presence of a sharp notch has a very adverse effect, and it has been observed that the tensile strength is more important than the ductility in withstanding repeated overloading.

Dr. Stout concluded his talk by pointing out that fabrication procedures are more likely to harm the ductility and notch toughness than the tensile strength.

Prior to the dinner and meeting, about 50 members of the Section visited the Tonawanda plant of the Chevrolet Motor Division, General Motors Corp., for a conducted tour.

Residual Stress and Distortion

Cincinnati, Ohio—L. C. Bibber AWS spoke before the regular meeting of the *Cincinnati* Section held on November 25th in the Engineering Society Headquarters. Mr. Bibber's subject "Effects of Welding on Residual Stress and Dimensional Changes in Steel" was one of the most interesting topics presented before this Section this year.

Mr. Bibber is a graduate of the University of Michigan. He has served as Senior Welding Engineer of the Bureau of Construction and Repair, U. S. Navy Department and is presently Welded Engineer of the U. S. Steel Corp., Pittsburgh, Pa.

Hard Facing

Cleveland, Ohio.—This season's third regular monthly meeting of the *Cleveland* Section was held on December 10th. Approximately 100 members and guests attended the dinner and technical session in the Hotel Allerton. House Committee Chairman, Harold Blum, has been able to make excellent arrangements with the hotel which provides a sociable meeting room and a good auditorium for the technical sessions. A large ballroom is taken over by the section, for whose meetings the hotel sets up a bar at one end and fills the remainder of the room with dinner tables. A raised platform is provided for the speakers' table from which the meeting is conducted. The dinner tables and bar are removed after the coffee talk and chairs are arranged for the technical session.

John Rogos, Membership Chairman, is continuing his active campaign to put Cleveland at the top of the list for new members. Nonmembers attending meetings are greeted at the door, registered and given a special colored lapel card. Rogos also gives a short "pep" talk at each section meeting reporting progress to date.

The coffee speaker for the evening, introduced by Howard Schell, was R. J. Ripberger, of the U. S. Treasury Department,

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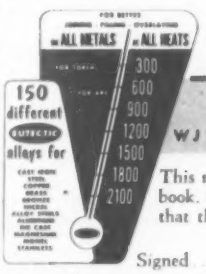

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PORTLAND, OREGON · PITTSBURGH, PA. · HOUSTON, TEXAS · MILWAUKEE, WISC.

who gave an interesting talk on how his department combats illegal narcotics traffic.

After a brief intermission to permit removing the dinner tables, Lew Gilbert, Program Chairman, introduced the technical speaker, Howard S. Avery AWS, research metallurgist with the American Brake Shoe Co. Mr. Avery's subject was "Hard Surfacing to Minimize Industrial Wear." He discussed various types of hard-surfacing alloys, explaining where and how to use them. His discussion was based on his own investigations of abrasion and impact testing to determine relative performance.

Mr. Avery has become widely recognized as an authority on hard surfacing, having received the Lincoln Gold Medal in both 1950 and 1952 for papers on "Hot Hardness of Hard Facing Alloys" and "Hard Facing for Impact." These papers were selected as having contributed most to the advancement and use of welding in 1950 and 1952. He has been active in the AMERICAN WELDING SOCIETY, having served on various specification committees and the Handbook Committee. He was Chairman of the AWS Filler Metal Subcommittee on Hard Facing Alloys.

Mr. Avery used slides to illustrate his discussion and opened the meeting to questions from the floor following his presentation.

Plant Visit

Dallas, Tex.—An interesting and enlightening plant visit was made on December 16th by 70 members of the *Dallas* Section to the Fritz W. Glitsch & Son's fabrication plant.

Prior to the plant visit members attended dinner at the Torch Restaurant after which an excellent movie on sports was shown.

Quiz Program

Denver, Col.—The second annual "Stump the Experts" program was held on December 9th by the *Denver* Section at the Oxford Hotel. David C. Card AWS acted as moderator with V. A. Schroer AWS, H. B. Klodt AWS, H. Jackson AWS, Herman Geller AWS and Robert B. Craig, Jr. AWS, as "Experts." The discussion was very interesting and the meeting was closed at 10:30 P. M. after about six questions were covered. The attendance of 27 at this meeting was below average but the interest of those present was high.

Chief C. J. Horan of the Denver Fire Department was the coffee speaker at the dinner preceding the meeting. Chief Horan spoke on the "Operations of the Denver Fire Department."

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Company Night

Detroit, Mich.—On December 12th the *Detroit* Section was guest of the Weltronic Co., at their main plant, for an evening of fun and education.

More than 550 members and guests had unlimited opportunities to inspect the full line of controls and other electronic devices which have made Weltronic a leading producer in this country.

The season spirit was well conveyed by many entertaining features, including door prizes and tasty refreshments.

The Sales and Engineering staff of Weltronic deserve the thanks of the Section for a gala evening.

Two popular OCD films, "The Atom" and "Plan for Survival" with actual Atomic Bomb photos, were shown.

Plant Tour

Fort Wayne, Ind.—Sectional steel dredges, shop welded, prefitted, disassembled for shipment, and assembled on the job in less than a week, were illustrated in a motion picture presented at the *Anthony Wayne* Section dinner meeting at Fort Wayne's Howard Johnson Restaurant on Nov. 21, 1952.

Walter W. Walb, president of the American Steel Dredge Co., gave a modest recital of the history of his company which developed barges for the Navy during World War II and instructed 14 other fabricators in the production of the barges. Other welded fabrications of extreme interest to the 75 members and guests were explained by engineers of the American Steel Dredge Co. and the large, new warehouse of the American Steel Supply Corp.

The members saw the Wayne Crane in process of manufacture, along with Hi-Clearance row-crop sprayers, collecting mains for steel mill coke ovens, and that amazing forest trailbreaker which chews up trees 6 to 8 in. in diameter, the Bushwacker.

Production of such heavy equipment, which is subjected to extremely rugged service, demands weldments that will take it, and quality is the theme throughout this organization. The Section is indebted to their host for a highly instructive evening, and doubly indebted for the emphasis placed by top officials on weld quality.

Christmas Party

Fort Wayne, Ind.—A Christmas Party was held by the *Anthony Wayne* Section for members and their wives on December 12th. A turkey and sea-food dinner at the Howard Johnson Restaurant was enjoyed by 38 people. A double octet from Central High School provided dinner music. The Christmas songs created the beautiful feeling that goes with Christmas.

A full color and sound movie, "God of

You won't need extra torch mixers when you use the modern welding equipment made by San Francisco's oldest producer of fine apparatus for flame cutting and gas welding.

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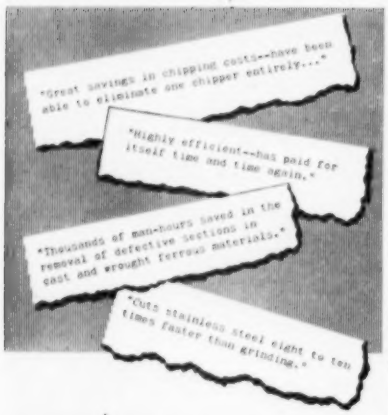
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"Highly efficient—has paid for itself time and time again."
"Thousands of man-hours saved in the removal of defective sections in cast and wrought ferrous materials."
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the Atom," featuring actual pictures of the Nagasaki and Bikini explosions was shown. The picture "Deep Horizon" made by the Shell Oil Co., showing the locating and drilling for oil, gave the membership an evening well spent.

Plant Tour

Grand Rapids, Mich.—About 90 members and guests of the *Western Michigan* Section took part in a well-prepared and conducted tour through the Shaw Box Crane Division of Manning, Maxwell & Moore Co., Muskegon Heights, Mich., on November 24th. There were plenty of guides to keep the groups small enough so that each person was close enough to his guide to ask questions and see the work being done first hand. At the completion of the tour soft drinks were served by the company. Everyone present agreed that this was one of the best meetings of the *Western Michigan* Section.

Dinner at the well-known Bill Stearn's Steak House was enjoyed by 80 members and guests prior to the tour.

Panel Discussion

Grand Rapids, Mich.—Members of the *Western Michigan* Section were guests of the American Society for Metals at a joint meeting held on December 15th in the Rowe Hotel. The meeting was in the form of a panel discussion. The AWS members on the panel were represented by Bob Kemp of the American Seating Co. and Jim Nyburg of General Motors Corp. The panel was composed of six members and covered every phase of metals and welding. Questions were asked and satisfactory solutions given. These panel discussions always prove very interestng and are looked forward to each year.

Inspection Tour

Houston, Tex.—An inspection tour of the new Brown and Root tank plant in Houston was held on December 16th. Tank hulls and turrets are outfitted in this plant and are shipped elsewhere for final assembly.

During the tour the members saw the welding of both light and heavy armor plate all being welded manually. Jigs and fixtures for the assembly and welding are a very important part of the procedures. Most of the large barrel jigs for positioning the hulls and turrets are made in the plant.

Many pieces of specialized machinery are used in performing the various machining operations on the armor plate. Of special interest were the large vertical turning and boring mills, the largest being a 29-ft machine.

Forty-eight members and guests enjoyed this most interesting and informative tour.

Christmas Party

Indianapolis, Ind.—Sixty-six members and guests of the *Indiana* Section had a most enjoyable time at a Christmas Party held on December 19th at the Severin Hotel. Paid entertainers, a magician and cartoonist sponsored by several members companies, made the evening a most pleasant one. Corsages were given to the ladies and each child received a balloon and a silver dollar.

Jet Aircraft Engines

Kansas City, Mo.—The *Kansas City* Section held their December 11th dinner meeting in Fred Harvey's Pine Room. There were 35 members and guests present at the 6:30 P.M. dinner.

Due to mechanical difficulties with the projector, the showing of films on jet fighter planes has been postponed until a future meeting.

Tom Boosinger, Section Engineer, Aviation Gas Turbine Division of Westinghouse Electric Corp., gave an illustrated talk on the operation and design of jet aircraft engines. The talk was of a general nature and was interesting to all.

A good question-and-answer period followed this presentation.

The meeting was adjourned at 9:30 P.M.

Coming Meetings

Milwaukee, Wis.—The regular monthly meetings of the *Milwaukee* Section for 1953 will be held on January 23rd, February 20th, March 27th and April 24th.

Arc Welding Electrodes

Newark, N. J.—The November 18th meeting of the *New Jersey* Section was held at the Essex House with 72 people in attendance. The guest speaker was R. K. Lee [illegible], Vice-President, Alloy Rods Co., York, Pa. His subject was "Modern Electrodes and Their Value in Solving Today's Welding Problems."

The principal part of the program was preceded by a film entitled "No Finer Electrodes Made Anywhere." This film showed the making of modern arc welding electrodes. It is believed to be the first time that the hitherto secret details of electrode manufacturing have been revealed.

Mr. Lee's talk was very informative and covered the arc-welding electrode field effectively. An interesting discussion followed. Mr. Lee received his Bachelor of Metallurgical Engineering degree from Ohio State University in 1935, and then spent five years as Research Engineer with the Steel and Tube Division of the Timken Roller Bearing Co. The past 12 years have been devoted to arc-welding elec-

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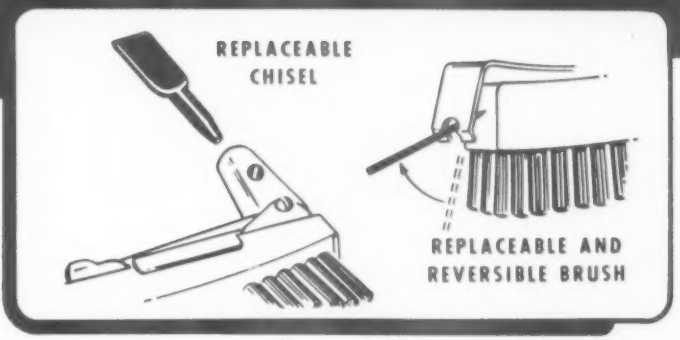

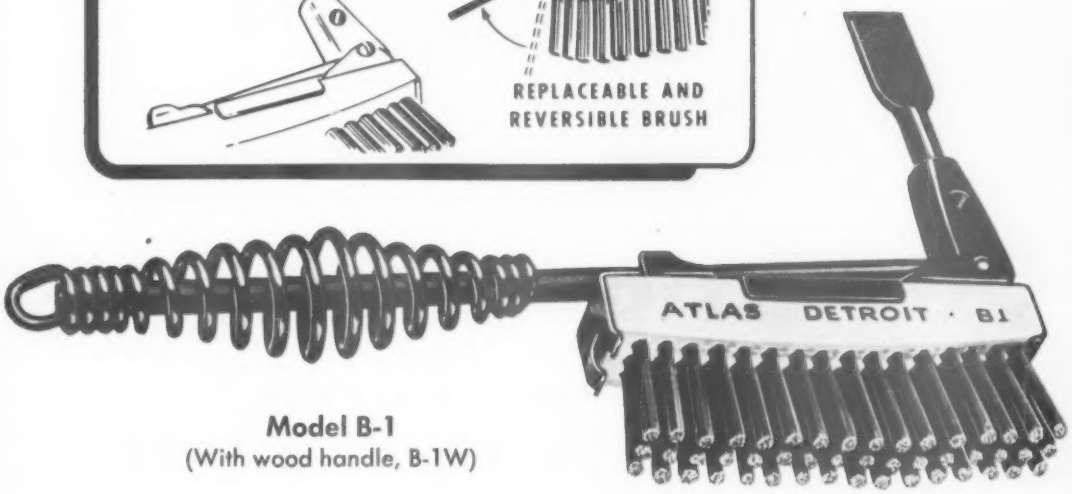

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● Experience real economy with this tool that requires replacement of worn parts only! The "Re-bit" chisel can be set at any angle, has a wider edge and narrower cross section, gets into corners and pockets better, affords better vision. "Re-bit" is easier to sharpen, lasts longer . . . Ask your welding supply dealer for information on all 27 Atlas models.

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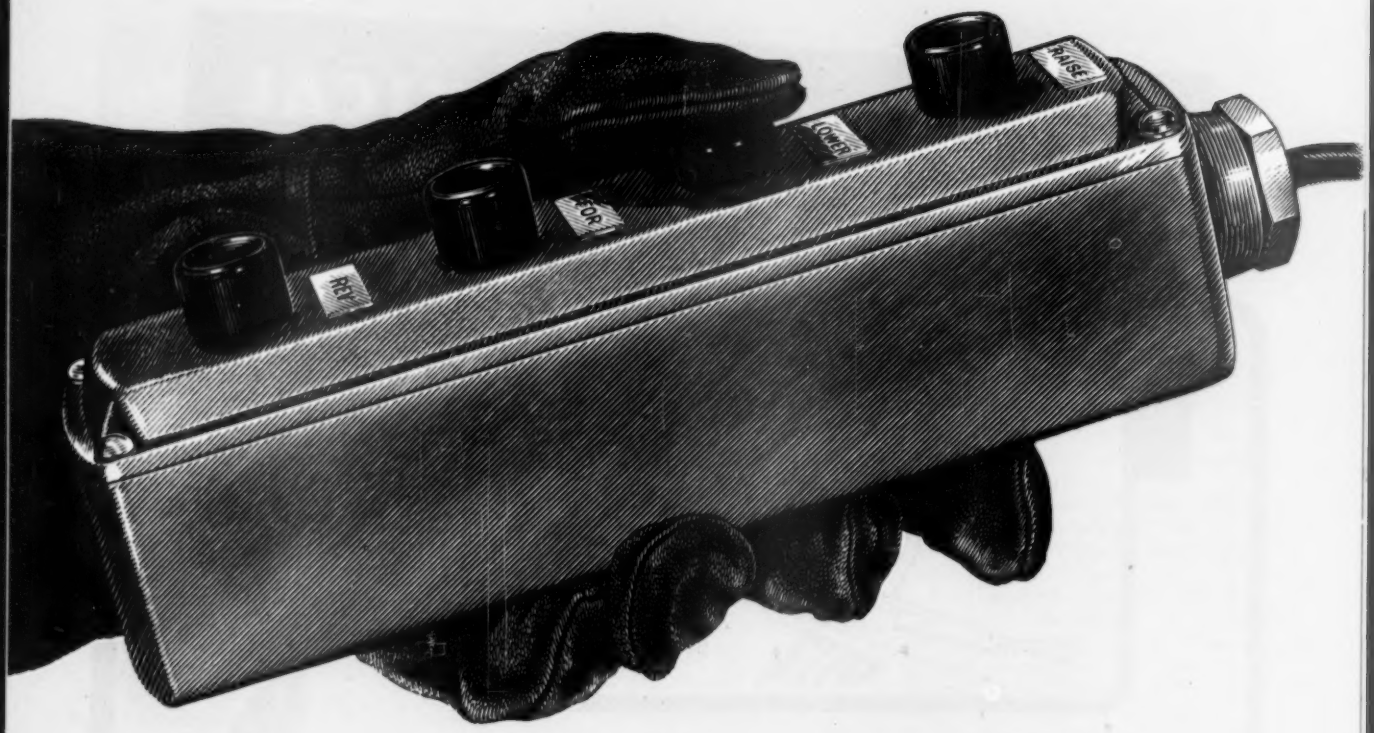

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Cut costs as much as 50% — position the weldment, not the operator! A touch of a control button does the work — saves handling time. Welding is downhand — permits using a larger rod for faster deposition. Welds are smooth, uniform. P&H Positioners are available in capacities from 2500 to 36,000 lbs. — remote-control and hand-operated models. Ask your P&H representative or distributor for further information — or write us.

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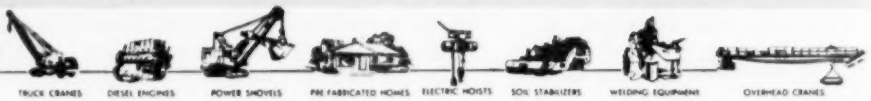

trode research and development, and during the past six years he has been associated with the Alloy Rods Co.

He is past chairman of the York-Central Pennsylvania Section of the AWS and is at present serving on several filler and metal specification committees of the AWS in New York. He is also serving on the Ordnance Advisory Committee on the Welding of Armor and the Classification and Color Chart Committee, Arc Welding Section, National Electrical Manufacturers Association.

In addition to the AMERICAN WELDING SOCIETY, he is a member of the American Society for Metals and the Engineering Society of York.

The usual after-meeting snack was enjoyed by all in attendance. The winner of the free dinner was G. G. Holbrook AWS who is connected with the Newark College of Engineering.

Jigs and Fixtures

Oklahoma City, Okla.—A. K. Pandjiris AWS of the Pandjiris Weldment Co. was the guest speaker at the October 30th meeting of the *Oklahoma City* Section held at the Barnes Club with an attendance of 65. Mr. Pandjiris gave an excellent presentation on the subject "Set the Pace—Win the Race" (gearing for high-speed production welding).

A fellowship period followed the meeting with the serving of coffee, beer and pretzels.

Pressure Vessels

Oklahoma City, Okla.—Dr. H. C. Boardman AWS, of the Chicago Bridge and Iron Co., Chicago, gave an excellent talk on the subject "Pressure Vessels—Design Now and in the Future" at the November 24th meeting of the *Oklahoma City* Section before an audience of 680 at the Biltmore Hotel. Dr. Boardman's applications and research talk was illustrated with slides.

Welding in Shipbuilding

Pascagoula, Miss.—"Welding in Shipbuilding—a Few Important Considerations" was the subject of a highly interesting nontechnical paper presented by Commander D. B. Henderson AWS, Secretary, Ship Structure Committee, at the December 3rd meeting of the *Pascagoula* Section before an audience of 58 members and guests.

An excellent sound color film on "The Master Element" was shown through the courtesy of the American Waterways Operators.

The speaker was introduced by Earl S. Shulters AWS of the United States Maritime Administration.

Plant Tour

Peoria, Ill.—An excellent plant tour of Wire Mill at Keystone Steel and Wire Co. was made by 64 members of the *Peoria* Section on December 17th. This trip consisted of a 2½-hr tour of the processing and manufacturing of wire products of coiled rods from the Bloom Mill through the various wire products manufactured.

The process consisted of wire drawing, surface treating for the manufacture of welding wire both bare and copper coated, drawing and processing wire both galvanized and galvanealed for use as lawn wire, chicken wire, wire mesh, concrete reinforcing mesh and others of this type using butt welding and automatic electronic controlled wire cloth weaving machines, drawing of bright and galvanized wire and manufacture of various types of nails. An interesting feature in this department was the use of 100-lb paper containers instead of customary wooden keg. It is claimed the paper container withstands ten drop tests whereas the wooden keg usually bursts on a single drop.

The tour was concluded in the fabricating and machine shop building where practically all of the processing machinery for manufacturing these products is fabricated by the company itself; such complicated and accurate equipment as a 9-drum high-speed draw bench of fabricated steel, approximately 5 ft high, 6 ft wide and 25 ft long.

The tour was thoroughly enjoyed by all in attendance and sufficient guides were supplied so that each group was furnished with proper information and time to inspect each process.

Pipe Line Films

Phoenix Ariz.—The December meeting of the *Arizona* Section was held at the Hotel Westward Ho, December 17th. Following the dinner, Barry Hunsaker, Project Engineer of the El Paso Natural Gas Co. of El Paso, Tex., presented a very interesting technicolor sound movie on a pipe liner's life in building a pipe line. The film also shows beautiful scenes of various points in the country and should be seen by all AWS Sections. Mr. Hunsaker was accompanied by Marshall Willis, Advertising Manager of El Paso Natural, who spoke a few words to the Section in a most interesting manner.

A second film "San Juan to San Francisco" presented the story of the multi-million dollar pipe line from the San Juan Basin in New Mexico to San Francisco, Calif. It vividly showed how El Paso Natural used Navajo Indian help by training and educating them and promoting friendly relations. This film, too, was chock full of beautiful technicolor scenes and should be seen by all AWS Sections.

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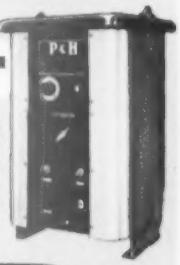
put welding in your plant on a low-cost, high-production basis



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Has P&H Dial-lectric Instantaneous Remote Control. Sizes up to 625 amps., NEMA rated. Connectable to 220 and 440 volts.

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Portable. Equipped with Dial-lectric Control. Runs at only 1750 rpm. Welding service range, 60-375 amps., NEMA rated.

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13 types that take the problem out of welding high-sulfur, free-machining, low-alloy, and high-strength steels; castings, etc.

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Welding Arcs

OLD G-E WELDERS? Some have been in this salt air for ten years but they still give top performance. Through the porthole a workman feeds cable to weldors (inset) deep in the hold—sometimes as far away as 300 feet. Don't miss the new G-E a-c sets.

DEPENDABLE G-E A-C WELDERS HELP SPEED U.S. SHIPBUILDING PROGRAM

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When you make your swing to a-c welding, swing to G.E., pioneer in a-c welding and still the leader. For equipment, electrodes, accessories, spare parts and service, call the local G-E Welding Distributor—see list next page, or look in the yellow pages of your telephone book under "Welding Equipment—General Electric." General Electric Co., Schenectady, N. Y. 710-1

GENERAL ELECTRIC

News

information on equipment, electrodes and accessories from G.E., pioneer in a-c welding

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Built for dependability and easier welding . . . on suggestions from G-E customers

1. Fast range-changing with new switch—no leads to unplug, no connections to make.

2. Quick inspection is easy. Remove the entire case in two minutes without disconnecting the primary leads.

3. You save on power with a case-mounted primary switch for turning off the current between welds.

4. Fast take-offs—no scratching or pecking. Weldors save time because automatic hotstart adjusts instantly to every setting.

5. Smooth arc is easy to control because arc-stabilizing capacitors eliminate popouts.

6. Case stays cool because the large fan gives every component adequate ventilation.

7. Pinpoint accuracy in current settings is easy with the wide, double current range.

8. Long coil life and trouble-free operation are built in with Class H Silicone insulation, able to take temperatures 30 per cent higher than ordinary insulations.

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Joe Magee says . . . Here's where to use low-hydrogen rods . . .

If you're looking for electrodes to weld high alloy steel, medium carbon steel and sulphur steel without underbead cracking and porosity, G-E W-32 low-hydrogen rods are your answer. These electrodes will weld equally well on a-c or d-c, and their high ductility and toughness will hold up exceptionally well at low temperatures. G-E W-32 is an excellent trouble-shooter for production welding, and it is ideal as a maintenance tool, too. Cost-wise, it is entirely practical to replace ordinary electrodes on some applications with G-E low-hydrogen electrodes which offer higher speeds and higher impact values.

The use of low-hydrogen electrodes is especially recommended for welding plate that must be enameled. The entrapped hydrogen resulting from the use of ordinary electrodes escapes after enameling and causes flaking. The use of G-E W-32 electrodes will practically eliminate this condition and save many hours of re-working.

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Now it's easy to switch to G-E electrodes. AWS classification and competitors' numbers available for 23 G-E stainless steel and 36 regular G-E electrodes on sturdy pocket-size slide-rule.

Available *only* through your G-E Welding Distributor. Ask him for one today!

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Colorado: Boulder, Colorado Springs, Denver, Durango, Ft. Collins, Ft. Morgan, Greeley, LaJunta, Longmont, Pueblo—Hendrie & Bolthoff

Florida: Ft. Pierce, Hollywood, Key West, Melbourne, Tampa, Vero Beach, West Palm Beach—Florida Gas & Chemical

Georgia: Atlanta, Macon—Welding Supply & Service; Augusta—Marks Oxygen & Welding Supply; Columbus—Williams Welding Supplies

Idaho: Boise—Olson Manufacturing

Illinois: Chicago, Moline, Morton—Machinery & Welder

Indiana: Evansville—Drill Master Supply; Ft. Wayne, Indianapolis, Richmond—Sutton-Garten; South Bend—Perry Welding Sales & Service

Iowa: Des Moines—Machinery & Welder

Kansas: Coffeyville—Thompson Bros. Supply & Welding Equip.; Hutchinson—Kopper Supply

Kentucky: Louisville—Reliable Welding, Paducah—Henry A. Petter Supply

Louisiana: Alexandria, Shreveport—Hughes Oxygen; New Iberia—Welders Supply; New Orleans—Equitable Equipment; Opelousas—Daigle Welding Supply, Lake Charles—Welders Equip.

Maryland: Baltimore—Arcway Equipment

Massachusetts: Boston—New England G-E Welding Sales Division

Michigan: Detroit—Welding Sales & Engineering; Grand Rapids—Miller Welding Supply

Minnesota: Duluth—W.P.&R.S. Mars; St. Paul—Production Materials

Mississippi: Jackson—Jackson Welding & Supply

Missouri: Kansas City—Hohenschild Welders Supply; St. Louis—Machinery & Welder

Montana: Billings—Valley Welders Supply, Butte, Great Falls—Montana Hardware

Nebraska: Lincoln—Lincoln Welding & Supply; Omaha—Baum Iron

New Jersey: Kenilworth—Welding Sales

New Mexico: Albuquerque—Industrial Supply City; Hobbs—Western Oxygen; Las Cruces, Silver City—Car Parts Depot, Inc.

New York: Buffalo—Welding Equipment Sales; Syracuse—Welding Engineering & Equip.

North Carolina: Charlotte—Dixie Gases, Gastonia—Gastonia Motor Parts

North Dakota: Bismarck, Fargo—Acme Welding Supply; Fargo—Dakota Electric Supply

Ohio: Akron, Cincinnati, Cleveland, Columbus, Dayton, Mansfield—Burdett Oxygen; Toledo—Odland Iron Works

Oklahoma: Tulsa—G-E Welding Sales Division

Oregon: Eugene, Portland—J. E. Haseltine

Pennsylvania: Philadelphia, Pittsburgh—Arcway Equipment

South Carolina: Columbia, Greenville—Welding Gas Products

South Dakota: Deadwood—Hendrie & Bolthoff

Tennessee: Chattanooga, Knoxville, Nashville—Welding Gas Products; Memphis—Delta Oxygen

Texas: Abilene—M&M Welding Supply; Alice, Corpus Christi—Crane Welding Supply; Alpine, El Paso, Marfa, Pecos—Car Parts Depot; Amarillo—Tex-Air Gas; Brownsville, Harlingen—Acetylene Oxygen; Dallas—Hill Equipment & Supply; Houston—G-E Welding Sales Division; Lubbock—Welders Supply; Midland—West Texas Welders Supply; Odessa, Pecos—Western Oxygen; Plainview—Plains Welding Supply; San Angelo—Southwestern Welding Supply; Snyder—Western Welding Supply; Texarkana—Hughes Oxygen; Wichita Falls—Nortex Welding Supply

Utah: Salt Lake City—The Galigher Co.

Washington: Seattle, Spokane—J. F. Haseltine

West Virginia: Bluefield—Bluefield Supply, Charleston—Virginian Electric, Huntington, Logan—Logan Hardware & Supply

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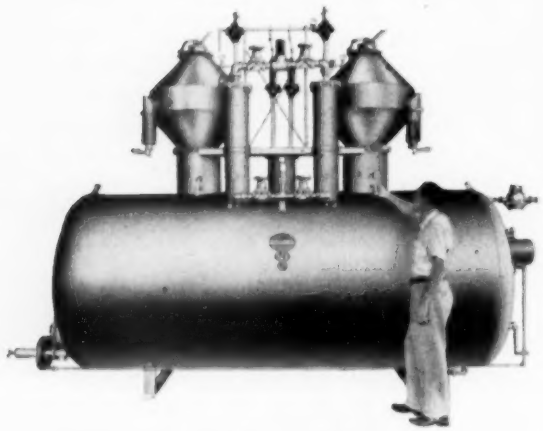
modern acetylene production



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WELDING Sight Feed EQUIPMENT

THE SIGHT FEED GENERATOR CO.

WEST ALEXANDRIA, OHIO, U.S.A.

The meeting was adjourned by the Chairman, Ralph Smith, after thanking Mr. Hunsaker and Mr. Willis for their fine program.

High-Temperature Piping

Pittsburgh, Pa.—R. W. Emerson (AWS), Metallurgist, Pittsburgh Piping and Equipment Co., presented a semi-technical paper on "Developments in Welding High-Temperature Piping" at the November 19th meeting of the *Pittsburgh* Section held at the Mellon Institute with an attendance of 114. Forty-seven were present at a get-together dinner at the Hotel Webster Hall.

Mr. Emerson discussed some of the metallurgical problems encountered in the welding of low-alloy and stainless steel piping including dissimilar metal joints for high-temperature applications, as encountered using the manual metallic-arc, submerged-arc, and Heliarc welding processes.

Applicable inspection methods such as radiography, ultrasonics, zyglo and magnaflux were discussed. These are not only used for the purpose of inspecting the finished product but as an aid to the welder. Zyglo and radiography have been used by and for the welder on critical jobs, to aid him in his effort to produce a sound weld.

Mr. Emerson was graduated from the University of Michigan in 1936. He was with the Westinghouse Electric Corp. for a period of three years on metallurgical problems before becoming associated with the Pittsburgh Piping and Equipment Co. as Metallurgist.

Mr. Emerson has been active in the work of the American Welding Society for many years and has served on various Committees for the Pittsburgh Section. He has also presented papers before many of the American Welding Society Sections.

Slides were used for illustrating the presentation and a selected sound movie was shown preparatory to the opening of the meeting.

An after-meeting feature was the showing, through the courtesy of the Allegheny Ludlum Corp., of an excellent sound color film entitled "Shining Heart."

ASME Pressure Vessel Welding Code

Rochester, N. Y.—**R. Milligan** (AWS), Supervising Engineer of the Ocean Accident and Guarantee Corp., Ltd., New York City, was the guest speaker at the November 17th meeting of the *Rochester* Section, held at the Rochester Turners Club. Mr. Milligan's talk covered welding qualifications for unfired pressure vessels with a brief description of various phases of the Code, namely, U-68, U-69 and U-70.

Mr. Milligan pointed out that the boiler welding codes are very essential to the

Engineer, Designer, Fabricator and the operation of such equipment for many reasons. Safety is considered a prime factor in the design and construction of such vessels.

He stated for the benefit of those who were not too familiar with Code requirements that it is the responsibility of the pressure vessel fabricator to demonstrate by making performance tests that a satisfactory weld can be produced. He first must qualify and record the welding procedure to be used and then qualify the welding operators in accordance with the established procedure before production welding can be performed by the operator.

Welding Qualifications, Sec. IX, a book formulated and published by the ASME Code Committee, is available and has recently been revised. It outlines all rules and regulations pertaining to the grouping of materials, procedure qualification, operator qualification, etc.

Information compiled and formulated has been accomplished by a large group of men with a vast knowledge of engineering and design ability gained over many years of experience. Many interesting slides accompanied his talk which was well received by all.

A question-and-answer period followed.

Preceding the meeting, a very sumptuous dinner was served to a good turnout.

Harry C. Reynolds, of the Rochester Better Business Bureau, presented the coffee talk and explained the purpose and operation of this organization.

Low-Hydrogen Electrodes

Rochester, N. Y.—James Norcross AWS Sales Manager of the Arcos Corp., was the guest speaker at the December meeting of the *Rochester* Section, held at the Rochester Turners Club. Jim needs no introduction to the welding industry; his vast amount of experience in the development and application of low-hydrogen electrodes makes him an authority on same. He stated that the need for such electrodes occurred during the last World War when substitutions for some critical alloys had to be made in the manufacture of electrodes and coatings to produce satisfactory weldments on armor plate, etc.

He stated that the success of low-hydrogen electrodes is dependent on the manufacturing, processing and packaging at the electrode plant. First, they must be properly baked in a controlled oven at temperatures adequate to exclude the maximum amount of moisture, then packed in airtight containers for protection against moisture reabsorption while in storage.

He advised that all users of such electrodes be equipped with adequate means of keeping rods dry until used. Recommended procedures, such as keeping within the recommended ampere range and leaning toward the high side with the use of a very short arc, should be strictly followed to obtain the optimum results. Electrodes smaller than $^{3}/_{32}$ in. in diameter are not advised for use on high quality welding due to probable excessive porosity. Many slides were shown to demonstrate procedures developed to eliminate porosity, base metal cracking, etc.

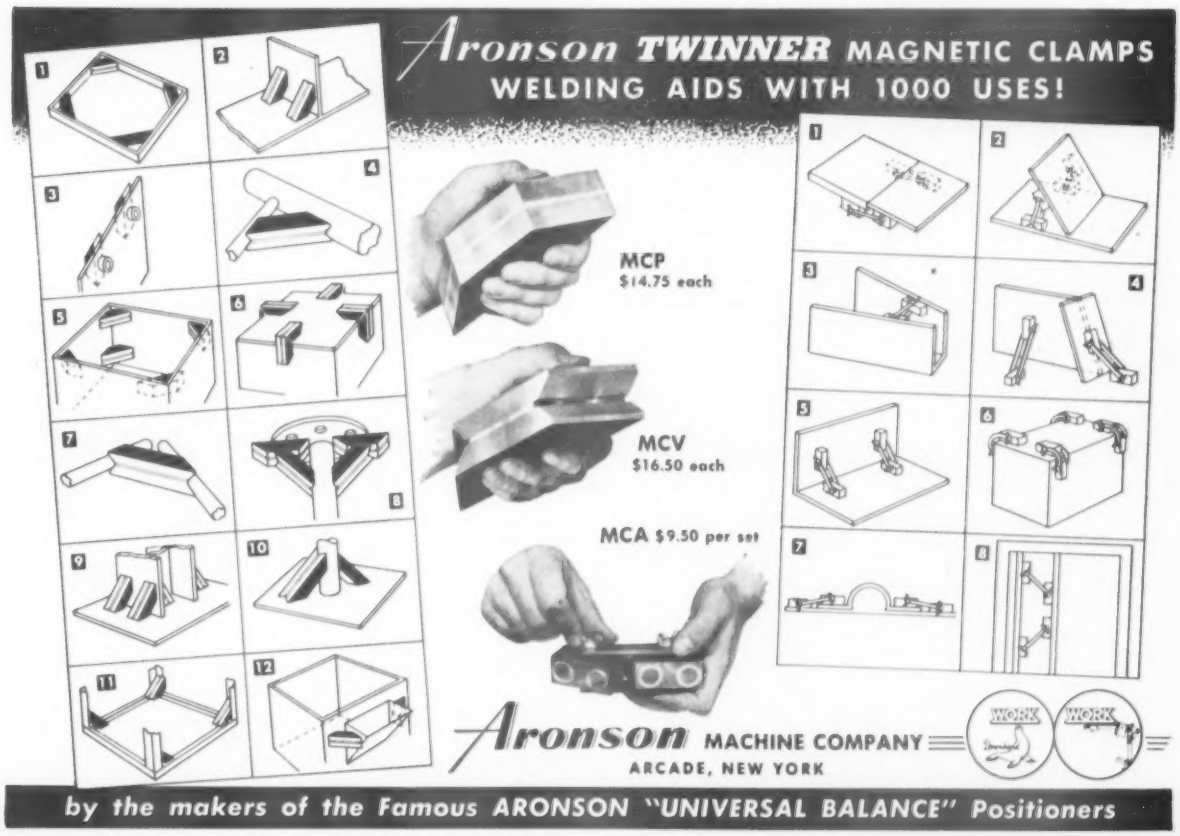
Jim emphasized the fact that low-hydrogen electrodes are definitely not a sure cure-all for everyone's problems. A very lively question-and-answer session followed, with many questions asked and very expertly answered.

Preceding the meeting, a very tasty chicken dinner was served to a good turnout.

John Teasdale, of the local Social Security Office, presented the coffee talk and explained our rights and benefits under this law, along with some very interesting data such as the fact that there are 183 persons over 95 years of age still working and drawing Social Security. Many questions were answered.

Job Shop Welding

Saginaw, Mich.—The *Saginaw Valley* Section held its regular monthly dinner meeting on December 11th at the High Life Inn with an attendance of 68. This meeting was of particular interest to job shop welders and those interested in



welder training. Robert Bereaw (AWS), Hobart Trade School, Troy, Ohio, who has taught thousands of students all types of welding, gave a very interesting talk on the subject "Job Shop Welding."

Annual Christmas Party

San Francisco, Calif.—One hundred and twenty-two members and guests of the *San Francisco* Section had a very enjoyable time at the Annual Christmas Party held on December 12th at the Lake Merced Golf and Country Club. This was the largest attendance at such a function in the history of the Section. A very entertaining program included a good fellowship period before the dinner followed by a floor show and last but not least the awarding of door prizes to the lucky winners.

Sigma Welding

South Bend, Ind.—A talk and demonstration on sigma welding was given by Robert J. Frick at the November 20th meeting of the *Michiana* Section.

Brittle Failure

South Bend, Ind.—"If the Charpy impact is 10 ft-lb or lower at 20° F, look out for trouble," so said William S. Pellini (AWS), Head of the Metal Processing Branch, Metallurgy Division, National Research Laboratory, Washington, D. C. speaking to a joint meeting of the *Michiana* Section, AMERICAN WELDING SOCIETY and the Notre Dame Section, American Society for Metals, held on December 10th. The title of Mr. Pellini's talk was "Factors Which Determine the Brittle Failure of Weldments." All of the work which has been done by Navy researchers since the first welded ship cracked at a pier has pointed to the fact that an unknown (at that time) property of the ship plate temperature transition must be measured in order to determine the suitability of the material to make a large welded structure that will not be likely to suffer a sudden crack as did many of the ships welded during World War II.

Mr. Pellini traced the history of the problem, which, while it also affects bridges and tanks, has had its greatest notoriety through ship failures. Of the 5000 welded ships built during the war period, about 1000 suffered fractures of some kind, and of these 1000, about 200 had major cracks develop. All in all, this is not a bad record considering that a radically new manufacturing method was suddenly put into mass production, with Tom, Dick and Harry, yes, and Pauline, too, welding with electrodes.

Two requisites appear to be necessary to start the fracture: (1) the steel must be notch sensitive at the existing temperature and (2) there must be a notch. The necessary notch may be an "arc strike," a small place where an electrode was inadvertently touched to a plate, thereby causing a small crack due to the extremely rapid cooling of a very small, hot spot. Or it may be a sharp corner in the design. Such a notch in a crack-sensitive plate, that is, one whose Charpy impact strength is less than 10 ft-lb, is capable of initiating a rupture. Once a crack is started, steels with impact values up to 30 ft-lb will maintain the rupture. But if the Charpy goes over this figure, the fracture changes to a ductile type and the energy required is at a level sufficient to stop progression of the rupture.

The Laboratory used a novel means of testing the steels. Plates were placed in an explosion chamber, supported around the rim, with an explosive above the center. The detonation bulged the plate. Varying numbers of explosions, depending upon the steel and notches put into the plates, will rupture the specimens. The type of rupture indicates the sensitivity of the material to brittle failure.

What can be done to prevent failures? Unfortunately, although it is now known what property of steel is to be avoided, the steel producers have not found out how to consistently produce tough plate. Therefore, the best plan is to test incoming shipments and segregate the sensitive steels. If these are used in relatively low-stressed

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Recently expanded production facilities enable us to accept applications for several choice territories. Exclusive assignment will be made to qualified representatives calling on and thoroughly acquainted in the jobber and dealer field and having a good background in welding equipment. We are a fast growing, well established organization manufacturing a complete, competitively priced line of arc welders. Prompt deliveries, lucrative commissions and full factory cooperation is assured. Inquiries invited from aggressive sales organizations handling related lines. Give full details in first letter. All replies confidential. Box V-285.

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A qualified applicant should:

a) have both theoretical and practical knowledge of welding, including experience with welding of alloy steels and aluminum.
b) know inert-gas welding and equipment.
c) have a thorough knowledge pertaining to the welding of API and and ASME code vessels and pressure piping codes.
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e) have experience in training and qualifying code welders.

Excellent salary, advancement and security. Travel is required. Outstanding opportunity with leading, progressive and expanding firm of engineers-constructors in petro-chem field with domestic and international activities.

Interviews arranged in New York at our expense. Arrangements for relocation of immediate families of selected applicants to NYC area.

Qualified applicants send complete detailed chronological resume, including salary history to Personnel Department:

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Take the case of the 2,000,000-gallon water tank erected by the Pittsburgh-Des Moines Steel Company at Niagara Falls, New York. A battery of D-C Rectifier Welders fed by one large diesel generator replaced a number of diesel-driven welding generators formerly used.

Maintenance was reduced 85%—weight was slashed by 15,000 pounds—initial cost was cut 50%—fuel savings totaled $8.70 a day!

For your welding application—large or small—call your nearest Westinghouse Representative or write Westinghouse Electric Corporation, Welding Division, Buffalo, New York.
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Westinghouse
D-C Welders

or compression-stressed areas, it will be safe to use them.

Resistance Welding

Syracuse, N. Y.—The *Syracuse* Section met on December 10th in the Hiawatha Room of the Onondago Hotel. Approximately 50 members and guests attended the dinner and heard the coffee speaker, T. F. Dundon, describe industry and life in modern Spain. The technical session met at eight o'clock and 130 members and guests heard R. T. Gillette [AWS], Precision Welder and Machine Co., describe the "Fundamentals of Resistance Welding." Mr. Gillette pointed out that there are four basic steps required to complete a spot welding cycle as follows: (*a*) Time for the electrodes to close and develop pressure to the work (Squeeze Time). (*b*) Time for the current to flow (Weld Time). (*c*) Time for the nugget to freeze after welding but before releasing the pressure (Hold Time). (*d*) Time to open the electrodes and move the work to the next position (Off Time).

In order to obtain uniform resistance welding results, the current cycle must be interrupted precisely at zero and then flow in an opposite direction from what it was when the cycle was interrupted. This control may be obtained with a synchronous timer.

There may be noncritical applications where synchronous timing may not be necessary, but consideration should be given to proper timing devices when welding special alloys and nonferrous materials.

When resistance welding, it is important to have scale, paint, rust, etc., thoroughly removed from the work by grinding, blasting with sharp grit or some similar method. Dirty material will produce erratic electrical characteristics and cause excessive deterioration of the electrodes.

An important factor in resistance welding is heat balance. Electrode material, diameter of contacting surfaces, electrical conductivity, and thicknesses of material must be properly selected in order to produce a weld at the faying surfaces.

High-Temperature Piping

Washington, D. C.—The regular monthly dinner meeting of the *Washington* Section was held on December 8th at Naylors Seafood Restaurant with an attendance of 40 at dinner and 75 at the meeting. Vincent T. Malcolm [AWS], Chapman Valve Manufacturing Co., was the guest speaker at the meeting. Mr. Malcolm presented a semitechnical talk on the subject "Fabrication of High-Pressure, High-Temperature Alloy Steel Piping by Welding." Slides accompanied the talk.

Coffee and doughnuts were served after the meeting.

Aluminum Alloys

Washington, D. C.—G. O. Hoglund [AWS], Aluminum Company of America, gave an extemporaneous, technical talk on the subject "Welding and Brazing of Aluminum Alloys" at the November 26th dinner meeting of the *Washington* Section. Mr. Hoglund used slides to illustrate his talk. A color film, "This Is Aluminum" was shown through the courtesy of the Aluminum Company of America.

Maintenance Welding

Worcester, Mass.—The November meeting of the *Worcester* Section was enthusiastic in its praise of William C. Henzlik [AWS], Associate Editor of the *Welding Engineer*, who presented a very interesting talk on "Maintenance Welding." This subject probably concerns a larger percentage of those interested in welding than any other division of the trade, and greatly pleased the 67 members and guests.

Mr. Henzlik illustrated his talk with slides and answered many questions from the floor. An interesting discussion was held on a debatable question with many comments coming from the audience.

A directors meeting was held after the general meeting under the direction of Clifford H. Murray, Chairman.

The *Worcester* Section at this time wishes to notify all its members of the change in meeting nights. Beginning in January the meetings will be held on the first Monday rather than the last Tuesday as has been the custom.

Membership Campaign

York, Pa.—Donald B. Howard [AWS], Mid-Western District Vice-President, helped inaugurate a membership drive for the *York-Central Pa.* Section at a special meeting held in December.

Mr. Howard who is Supervisor of Technical Services for the American Car and Foundry Co., Berwick, also presented a technical talk at this meeting. His present duties include trouble shooting and proceeds development in war materials products now being undertaken by this firm.

The purpose of the meeting was to receive instructions for the current membership drive from Charles H. Pyle, chairman of the local group. Among those who attended from the York area were: Frank A. Logue, Charles H. Pyle, Donald B. Howard, William L. DeLong, Charles W. Allen, G. Earl Jennings, Robert T. Luckenbaugh, Jack Cavanaugh. W. B. Hess, C. E. Lewis Kerchner, Donald McDivitt, Paul Lang, J. Frank Powl, L. B. Martin, Dick Lee, William C. Zinkaul, L. H. Kemper, Paul L. Stumpf and L. Ames.

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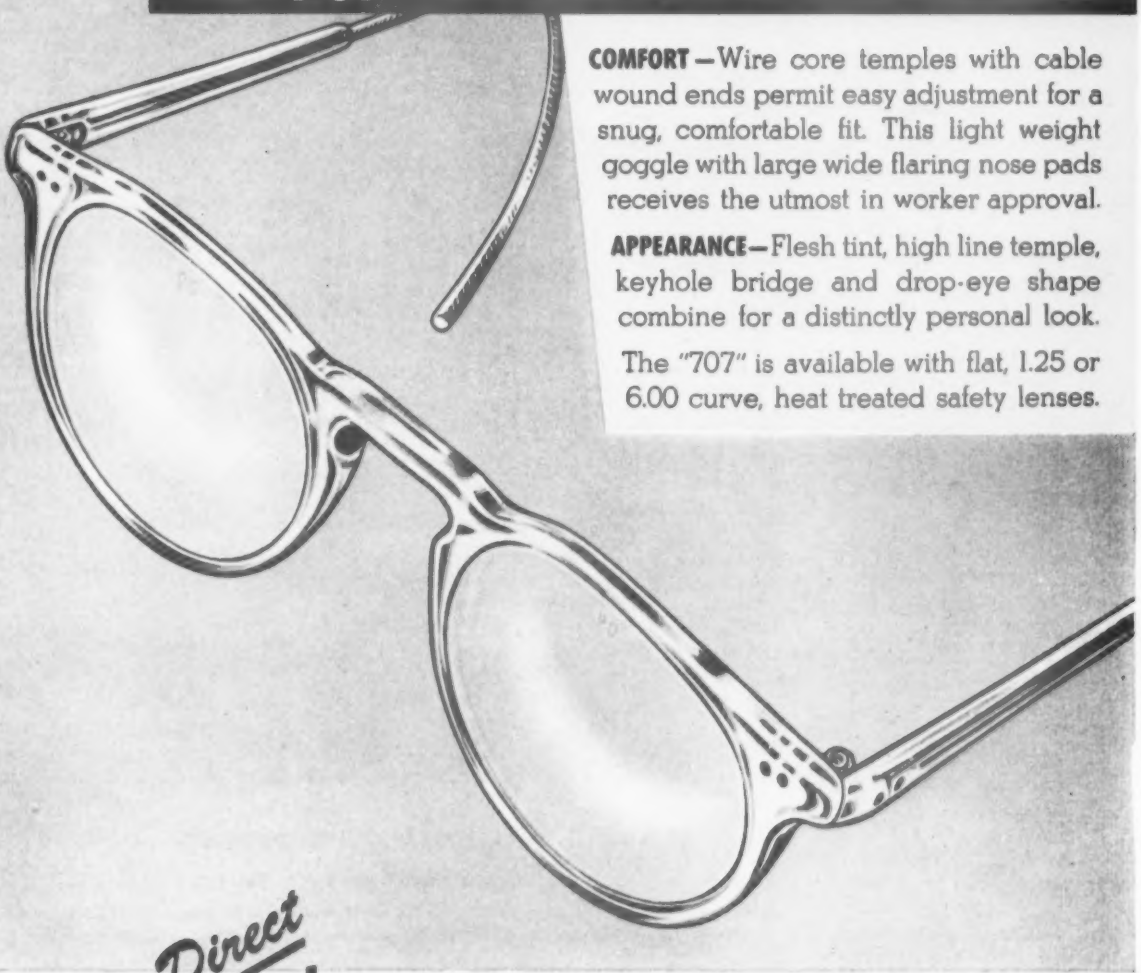

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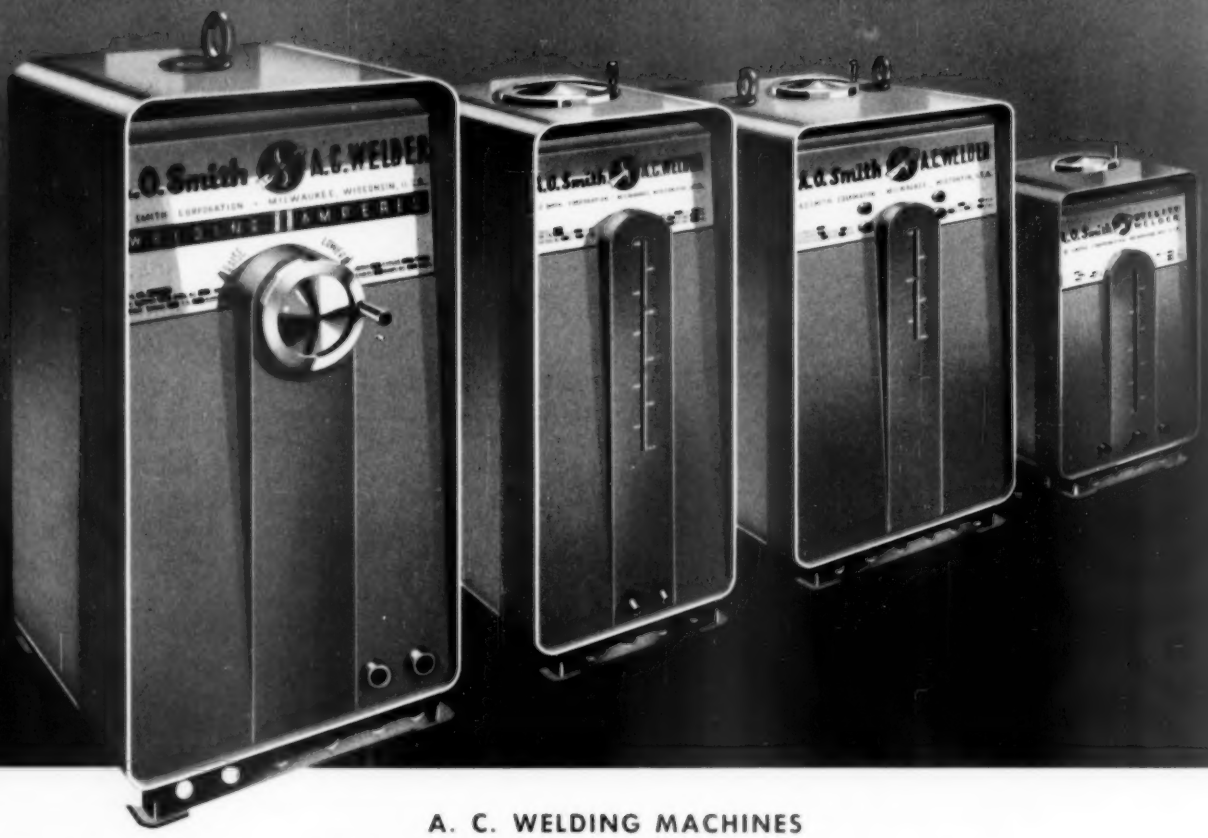

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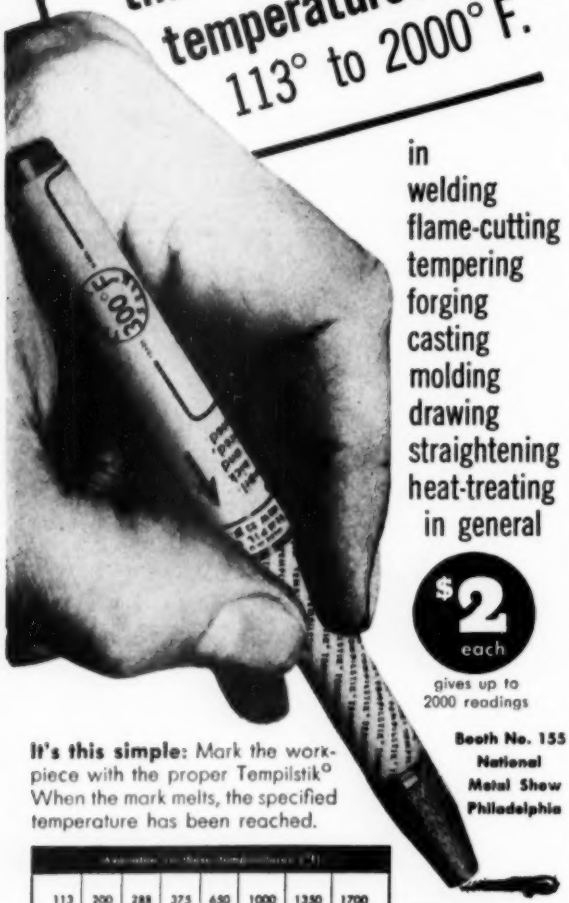

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Supplement to the Welding Journal, February, 1953

Practical Aspects of Welding Titanium Alloys

Welding of commercial titanium alloys with processes and equipment available for industrial applications

by J. J. Chyle and I. Kutuchief

THE investigation was conducted under a contract with the Watertown Arsenal, Ordnance Department, Contract No. DA-11-022-ORD-137, to study the problems involved in the welding of commercial titanium alloys, with the processes and equipment which are currently available for industrial applications.

Considerable attention has been given to the latest addition of a new industrial metal, namely titanium, because of its unusual combination of strength, lightness and corrosion resistance, not found in other metals. Tests on commercially pure titanium metal and its alloys have shown that it can be formed into various shapes and products to replace similar products of alloy steels and nonferrous metals. Its high corrosion resistance to sea water, nitric acid, chlorine and other corrosive media has placed titanium in an enviable position for many industrial applications. To increase the tensile strength of comercially pure titanium, of approximately 60,000 psi, alloying elements such as carbon, oxygen, hydrogen, chromium, molybdenum, manganese, aluminum, vanadium and others have been added in relatively small amounts so that titanium alloys with tensile strengths up to 180,000 psi have been developed for industrial applications.

In the fabrication of aircraft component parts and chemical equipment by welding, special problems have been encountered because of the high affinity of titanium with oxygen, nitrogen and hydrogen. The violent reaction of titanium with oxygen, nitrogen and hydrogen excludes the use of some of the fusion welding processes which are available, such as oxy-acetylene welding, the metal-arc coated electrode process, thermit welding, submerged arc welding and atomic hydrogen welding. In this investigation the inert-gas tungsten electrode metal-arc process was considered because of the availability of the equipment and the inertness of the gases to reactions with titanium metal. The inert-gas metal-arc consumable electrode process was not considered because this investigation was being conducted as part of a contract of the Ordnance Department with another laboratory.

This report represents, primarily, a progress summary and presents data which have been investigated for approximately one year, and includes all of the important results obtained up to Sept. 1, 1952.

The materials were furnished by Watertown arsenal and consisted of $^1/_2$- and $^5/_8$-in. thick plates of alloys developed by Titanium Metals Co., Rem-Cru Co. and Republic Steel Co.

These alloys were Ti-150A, Ti-XCM, RC-130A and RC-130B and Republic Steel alloys, Ti – 4% Cr, 2% Fe and Ti – 7% Mn alloy. Filler wire was furnished in $^1/_8$-in. diam size of Ti-75A, Ti-100A and Ti-150A, and Rem-Cru alloy RC-130A and RC-130B. For Ti-XCM and Republic Steel alloys, filler metal in the form of strips removed from the plate stock by sawing was used in making the welds.

SCOPE OF INVESTIGATION

The scope of this investigation using the inert-gas tungsten electrode metal-arc process included factors and welding procedures such as scarf design, direction of travel (backhand or forehand), selection of helium or argon gases and the sequence of layer deposition.

This investigation also included welding in completely controlled inert gas protection, the effect of heat treatment on the mechanical properties, radiographic examination, determination of the mechanical and physical properties of the welds and chemical analysis of the weld metal and parent stock.

Metallurgical examination of the parent material and weld metal has been initiated and is in progress, but will not be discussed at this time.

WELDING PROCEDURE

In view of the fact that the titanium alloys are classified as nonferrous type of metals, the initial step was to evaluate

J. J. Chyle is Director of Welding Research and **I. Kutuchief** is Senior Welding Engineer with the A. O. Smith Corp., Milwaukee, Wis.

Paper was presented at the Thirty-Third National Fall Meeting, AWS, Philadelphia, Pa., week of Oct. 20, 1952. Closing date for discussion Apr. 15, 1953.

the possibility of adapting the welding procedure used for the nonferrous metals, such as aluminum and copper. On the bases of extensive "know-how" with the inert-gas tungsten electrode metal-arc welding process and its industrial use, this process was selected as the one most suitable for welding of titanium and titanium alloys.

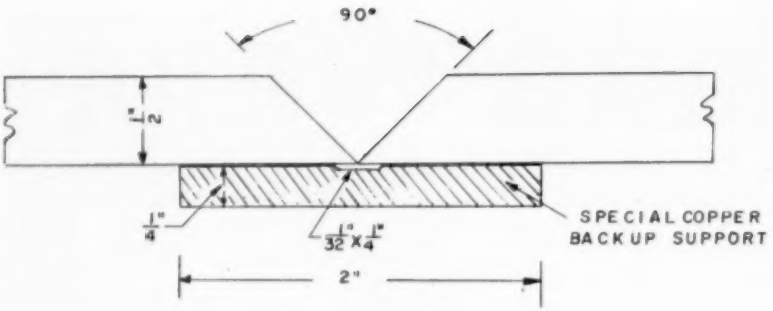
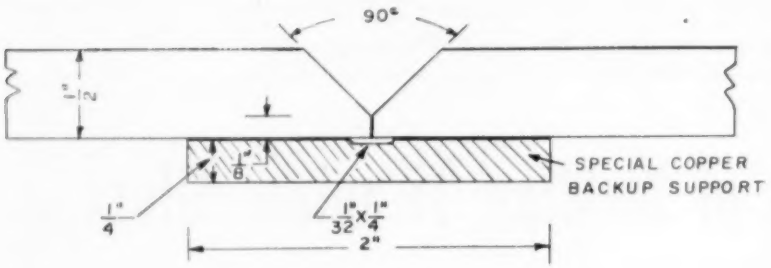


Fig. 1 Welding groove design used for test plates in the investigations



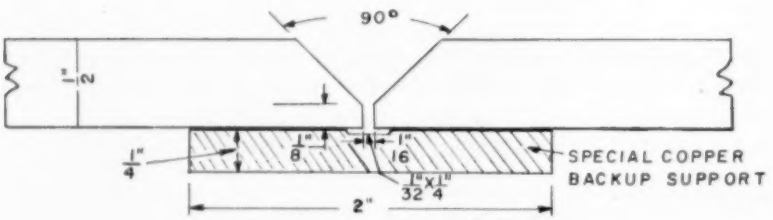


Fig. 2 Modifications of scarf designs tried for test plates in the investigations

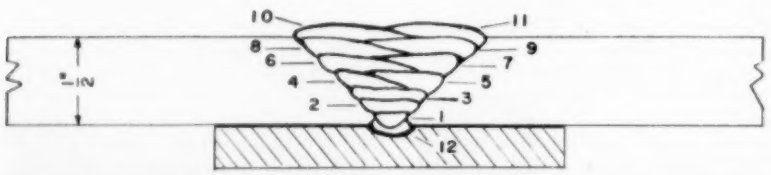


Fig. 3 Sequence of deposition

Fig. 4 Assembly of titanium alloy plates for welding, showing the hold-down bars, backup support, Heliarc torch and filler wire

Initial welding tests were made with a scarf design as shown in Fig. 1. The scarf design using a feather edge was used in order that complete penetration without the use of filler metal in the first layer could be obtained. The scarf designs shown in the other two sketches (Fig. 2) were tried and indicated that other groove modifications were satisfactory and could be applied in a commercial manner. The deposition of subsequent beads is shown in Fig. 3. Forehand and backhand travel of the welding torch was tried and it was found that both methods were satisfactory, but there is a preference for the forehand method because of greater visibility and ease of operation for the operator.

A study was made to determine the characteristics of helium and argon for shielding gases. The tests indicated that helium was more suitable as a shielding gas because with it the speed of welding was materially increased. It was estimated that the speed of welding was from two to three times greater with helium than with argon.

The plate materials furnished were in $^1/_8$-in. thicknesses and approximately 6 x 12 in. in dimension. A typical assembly for test plates is shown in Fig. 4 and illustrates the manner in which the plates were held down with hold-down clamps. No attempt was made to restrain the plates severely, except by the hold-down clamps. Conventional inert-gas torches were used, as shown in the photograph. Both types of welding current were used, a c and d c. The welding tests were made with d c using $^3/_{32}$-in. diam thoriated tungsten electrode on negative polarity. A typical welding procedure is shown in Table 1.

The plates were assembled on a special copper support over a groove in the copper backup to approximately $^1/_{32}$ x $^1/_4$ in. In addition, this backup had numerous holes drilled into the groove for the admission of inert gas shielding on the back side of the plate. After the welds were completed from the top, the back or bottom side of the weld was ground slightly, approximately $^1/_{32}$ to $^1/_{16}$ in. in depth, and welded with one layer, adding filler material of the respective composition to deposit sufficient metal for weld reinforcement.

Table 1—Welding Procedure

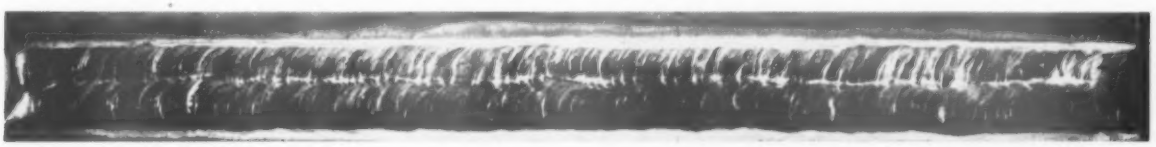
Welding torch: Type WGS 20M (200 amp), General Electric Co.
Tungsten electrode: $^3/_{32}$-in. diam thoriated type
Inert gas: Helium, 8 lpm flow in torch and 1 lpm for backup
Welding power: Constant potential, d-c electrode on negative polarity
Welding technique: Forehand travel
Preheat temperature: None
Interpass temperature: 130 to 190° F
Amperes: 140 to 155
Volts: 18 to 23
Postwelding heat treatment: None, except as given in text. Test plates were allowed to cool normally to room temperature

Photographs of the completed welds are shown in Fig. 5, showing the typical surface appearance of the welds. The welds were made in Ti-150A stock with Ti-75A filler wire, and no cracks occurred in the weld metal.

With respect to the welding of RC-130A and RC-130B alloys, there was some indication of cracking occurring after the welds were completed. Photograph (Fig. 6) shows welds made in RC-130A alloy with RC-130A filler metal. No cracks have occurred in the upper weld specimen after 20 days of observation. In the lower sample a transverse crack occurred across the weld 3 days after welding. In the RC-130B alloy considerable amount of cracking occurred transversely to the direction of welding, in some cases immediately after welding, and in others, within 24 hr after welding. This cracking in the RC-130B alloy occurred whether the alloy was welded in the open air or in a specially constructed chamber. It was found that stress relieving the weld at 1200° F for 1 hr after welding prevented the formation of the transverse cracks.

MACRO EXAMINATION OF WELDS

A typical macrophotograph of a weld made in $^1/_8$-in. Ti-150A alloy plate is shown in Fig. 7. This macrophotograph shows the coarse cast dendritic structure of the weld metal and also the increase in grain growth at the junction line of the weld and parent stock and in the heat-affected zone in the parent material. In this photograph it is apparent that the plate material on one side had a different rolling direction than the other side, as shown by the etch pattern in the parent stock.

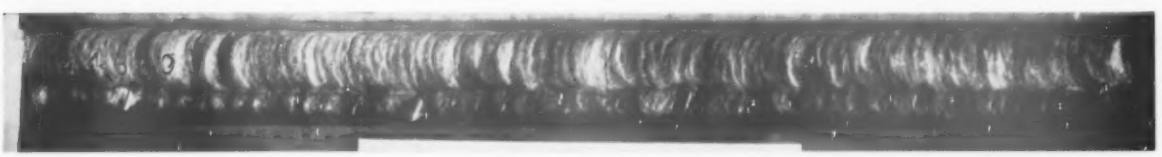


Test No. 42956. Type of plate: $^1/_8$-in. Ti-150A. Type of filler: Ti-75A. Condition: As-welded. Date welded: Nov. 22, 1952. No cracks have occurred since welded

Test No. 43194. Type of plate: $^1/_8$-in. Ti-150A. Type of filler: Ti-75A. Condition: As-welded. Date welded: Dec. 14, 1951

Figure 5

Test No. 44411. Type of plate: Ti-130A. Type of filler metal: Ti-130A. Condition: As-welded. No cracks have occurred after 20 days since welded.



Test No. 44559. Type of plate: Ti-130A. Type of filler metal: Ti-130A wire. Condition: As-welded. Transverse crack occurred 3 days after welding

Figure 6

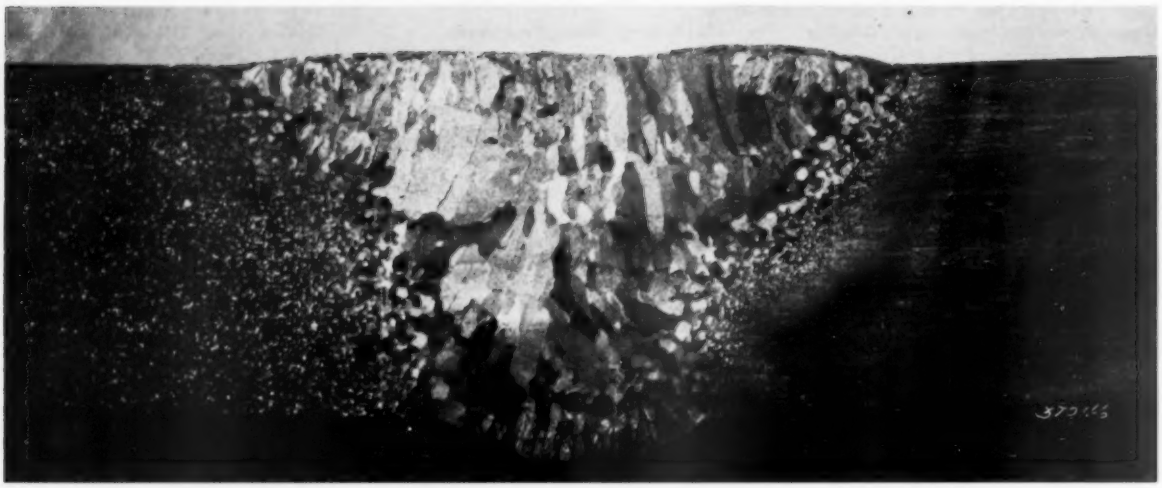


Fig. 7 Photomacrograph of weld cross section representing 1/2-in. Ti-150A plate material and Ti-150A weld metal in the as-welded condition

As is typical in nonferrous weld metal, there is no sharp demarkation between layers and there is a gradual blending of the columnar structure from one layer into the succeeding layers.

COMPOSITION OF COMMERCIAL TITANIUM ALLOYS

The various titanium alloys which were furnished to us in 1/8" and 5/8-in. plate thickness for this investigation, are listed in Table 2.

Table 2—Composition of Titanium Alloys (Commercial Specifications)

Type of alloy	*Alloying elements, %*						
	Cr	*Fe*	*Mn*	*Al*	*Mo*	O_2	N_2
Ti-150A	2.7	1.3	...	...	...	0.25	0.02
RC-130A	...	...	7.0	...	...	...	...
RC-130B	...	...	4.0	4.0	...	...	...
Ti–7% Mn	...	...	7.0	...	...	...	...
Ti–4% Cr–2% Fe	4.0	2.0	...	...	...	...	...
Ti–XCM	4.0	...	...	...	2.0	...	...

This table shows the commercial alloys from Titanium Alloys Co., namely Ti-150A, which is a chromium-iron-oxygen-nitrogen alloy, the titanium alloy Ti-XCM which contains 4% Cr and 2% Mo, the Rem-Cru alloy RC-130A which is 7% Mn alloy and the Rem-Cru RC-130B which is 4% Mn and 4% Al. The Republic alloy Ti – 7% Mn which is similar to RC-130A and the Republic Ti – 4% Cr, 2% Fe which is a straight chromium-iron alloy.

Typical radiographs of the parent stock are shown in Fig. 8. These radiographs show segregations depicted as lighter spots because of their greater density or greater absorption to the X-rays which were found in Ti-150A plate material alloy. Typical radiographs of welds are shown in Fig. 9. The upper sample represents a weld in Republic Ti–7% Mn alloy, while the lower represents a weld in Republic alloy 4% Cr, 2% Fe. The radiographs indicate segregations in the plate material, which in the upper radiograph the segregations are striated in a transverse direction to the

Fig. 8 Radiographs of titanium alloys which show segregations in the plate material

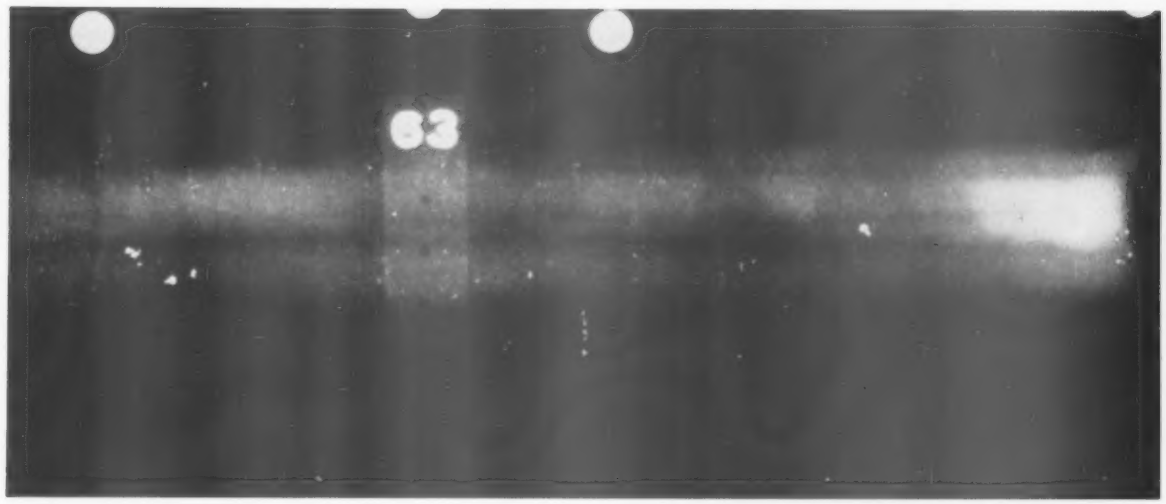


Fig. 9 Radiographs of titanium alloys which show segregations in the plate material

longitudinal weld seam. The segregations in the plate material of the lower weld are parallel to the longitudinal direction of the weld. The radiographs of both welds are considered satisfactory, in that they are free from porosity, slag inclusions and cracks. The upper weld shows a few isolated spots of tungsten inclusions. In general, the soundness of all welds made in the different alloys are quite comparable to those shown in the above two welds. The soundness of the welds in all the titanium alloys investigated was found to be satisfactory and compares favorably to radiographic standards of high quality welds in steel plate.

PHYSICAL AND MECHANICAL PROPERTIES OF WELDS AND PARENT STOCK

The mechanical properties were determined on the welds by making all-weld tensiles, joint tensiles and bend tests across the weld. The results of these mechanical properties are shown in Table 3. As may be noted, the welds were tested in the as-welded condition with the exception of the specimens where a special postwelding heat treatment was given as indicated. The results of the mechanical tests indicated that tensile strengths equivalent to the parent stock were obtained. Ductility, as measured in the joint tensile tests, was low and it is believed that the elongation occurred in the parent stock.

Bend tests, which were made as shown in Tables 4 and 5, indicated poor ductility for all alloys except Ti-XCM when given the special heat treatment, which consisted of heating at 1350° F for ½ hr, furnace cooling to 1150° F and water quenching. Table 6 also indicates the effect of this special heat treatment on the Charpy impact and bend ductility of the Ti-XCM alloy. The data in the table

Table 3—Mechanical Properties of Titanium Alloys

			0.375-in. diam joint tensiles				
Type of plate	*Type of filler*	*Heat treatment*	*Yield strength, psi*	*Tensile strength, psi*	*% Elongation in 1.4 in.*	*Reduction of area, %*	*Remarks on failure*
Ti-150A	Ti-150A	As-welded	154,200	158,600	7.2	16.0	In stock
Ti-150A	Ti-150A	1300° F, 1 hr, air cool	148,000	151,000	10.7	2.0	In weld
Ti-150A	Plate only	As-received	145,000	156,700	18.6	45.2	.....
Ti-150A	Plate only	1300° F, 1 hr, air cool	147,800	155,800	20.7	43.0	.....
Ti-150A	Ti-75A	As-welded	119,000	131,500	5.7	17.5	In weld
Ti-150A	Ti-75A	1300° F, 1 hr, air cool	121,900	130,900	3.6	9.0	In weld
RC-130A	RC-130A	As-welded	123,200	146,200	3.6	.....	Edge of weld
RC-130A	RC-130A	1300° F, 1 hr, air cool	125,800	140,700	5.7	.....	Edge of weld
RC-130B	RC-130B	As-welded	121,506	152,500	2.1	.....	Edge of weld
RC-130B	RC-130B	1300° F, 1 hr, air cool	137,200	147,300	3.6	.....	Edge of weld
Ti–4% Cr–2% Fe	Ti–4% Cr–2% Fe	As-welded	134,100	146,000	3.6	3.5	In stock

Table 4—Mechanical Properties of Titanium Alloys

			Bend specimens		
Type of plate	*Type of filler*	*Heat treatment*	*% elongation in weld*	*Degree of bend*	*Remarks*
Ti-150A	Ti-150A	As-welded	None	0	Failed in weld, brittle
Ti-150A	Ti-150A	1300° F, 1 hr, water quench	8.0	8	Failed in weld
Ti-150A	Plate only	As-received	.....	30	Failed
Ti-150A	Plate only	1300° F, 1 hr, air cool	.....	40	No failure
Ti-150A	Ti-75A	As-welded	None	0	Failed in weld, brittle
RC-130A	RC-130A	As-welded	None	0	Failed in weld, brittle
RC-130A	RC-130A	1300° F, 1 hr, air cool	None	0	Failed in weld, brittle
RC-130B	RC-130B	As-welded	None	0	Failed in weld, brittle
RC-130B	RC-130B	1300°F, 1 hr, air cool	None	0	Failed in weld, brittle
Ti–4% Cr–2% Fe	Ti–4% Cr–2% Fe	As-welded	None	10	Failed in weld, brittle

Table 5—Mechanical Properties of Titanium Alloys

Type of plate	Type of filler	Heat treatment	0.375-in. diam joint tensiles: Yield strength, psi	Tensile strength, psi	% elongation in 1.4 in.	Reduction of area, %	Remarks on failure
Ti-XCM	Ti-XCM	As-welded	106,000	110,800	12.9	59.4	In stock
Ti-XCM	Ti-XCM	As-welded	106,400	110,400	14.3	60.4	In stock
Ti-XCM	Ti-XCM	1350° F, 30 min, furnace cool to 1150° F, water quench	102,900	107,900	15.0	62.4	In stock
			0.357-in. diam all-weld tensiles				
Ti-XCM*	Ti-XVM*	1350° F, 30 min, furnace cool to 1150° F, water quench	110,100	118,900	11.4	16.9	.....
Ti-XCM†	Ti-XCM†	1350° F, 30 min, furnace cool to 1150° F, 30 min, water quench	124,100	137,100	9.3	16.1	.....
			Bend specimens				
			% elongation in weld	Degree of bend		Remarks	
Ti-XCM	Plate only	As-received	60.0 in 1/2 in.	160		No failure	
Ti-XCM	Ti-XCM	As-welded	1.5	5		Failed in weld	
Ti-XCM	Ti-XCM	1350° F, 30 min, furnace cool to 1150° F, water quench	9.3	30		No failure	
Ti-XCM	Ti-XCM	1350° F, 30 min, furnace cool to 1150° F, water quench	11.0	32		No failure	

* Welded in chamber.
† Welded in open atmosphere.

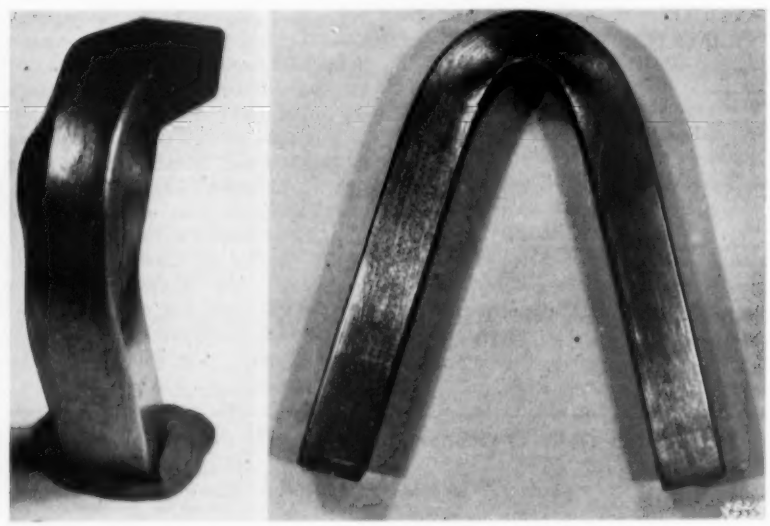


Figure 10

Test No. 27005. Bend specimen of special titanium alloy ht. L878, tested in the as-received condition, which disclosed 60% elongation in 1/2-in. gage lines after bending it to 160-deg angle. As-free bend.

also indicate the excellent ductility of the Ti-XCM plate material in the as-received condition, which was bent to a 160 deg angle with no failure. The elongation in 1/2-in. gage length measured 60%. The extent of bending is shown in Fig. 10.

In Fig. 11 are shown joint tensile specimens in titanium alloy Ti-XCM, showing excellent reduction of area in the specimens and elongation with failure occurring in the parent stock with reduction of area

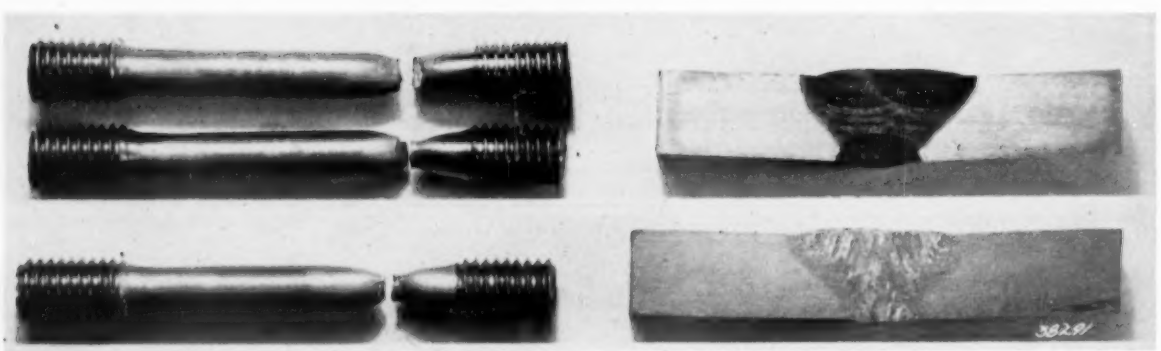


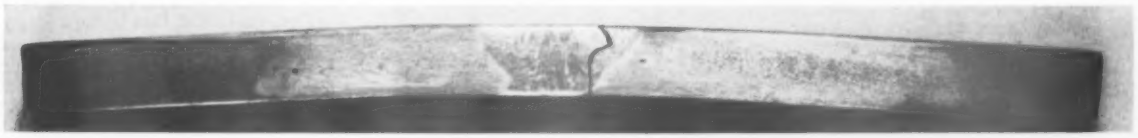
Figure 11

Test No.	Type of plate	Type of filler	Heat treatment	0.357-in. diam joint tensiles: Yield strength, psi	Tensile strength, psi	% Elongation in 1.4 in.	Reduction of area, %	Remarks
44771-1	Ti-XCM	Ti-XCM	As-welded	106,000	110,800	12.9	59.4	Failed in stock
44771-2	Ti-XCM	Ti-XCM	As-welded	106,400	110,400	14.3	60.4	Failed in stock
44771-3	Ti-XCM	Ti-XCM	1350° F, 30 min, furnace cool to 1150° F and water quench	102,900	107,900	15.0	62.4	Failed in stock

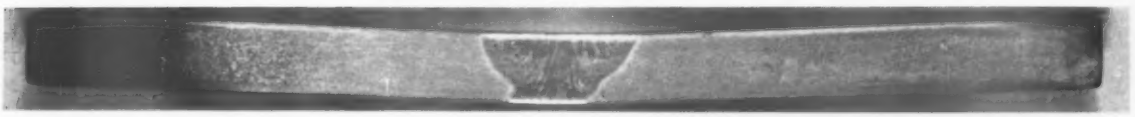
Table 6—Mechanical Properties of Titanium Alloys

				V-notch Charpy impact specimens			
						Vickers hardness (30 kg.)	
Type of plate	*Type of filler*	*Heat treatment*	*Location of notch*	*Energy of rupture, ft-lb at 75° F*		*Stock*	*Weld*
Ti-XCM	Plate only	As-received	In stock	179.6, 153.6, 141.8		256–270	
Ti-XCM	Ti-XCM	1350° F, 30 min, furnace cool to 1150° F, 30 min, water quench	In weld	21.2, 17.7, 25.9		252–260	301–318
Ti-XCM*	Ti-XCM*	As-welded	In weld	13.2, 11.9, 14.1		260–265	370–385
Ti-XCM*	Ti-XCM*	1350° F, 30 min, furnace cool to 1150° F, water quench	In weld	43.1, 43.1, 34.1		263–269	272–293

* Welded in chamber.



Test No. 44771-1. Type of plate: ½-in. Ti-XCM. Type of filler: Strips of Ti-XCM. Condition: As-welded. Bend failure: In weld.



Test No. 44771-2. Same type of bend specimen but not tested.

Test No. 44771-3. Same type of bend specimen which was heat treated at 1350° F for 30 min, furnace cool to 1150° F and then quench in water.

Figure 12

of 59 to 62%. The upper macrograph in this figure was taken of the weld in the as-welded condition, while the lower one was taken after heat treatment, as indicated.

The effect of special heat treatment on the bend ductility is shown in Fig. 12. In the as-welded condition the bend specimen revealed 0% elongation with a brittle fracture through the weld. The effect of special heat treatment on the bend ductility is shown in the lower bend test, and shows a bend of 30 deg without failure.

WELDING IN INERT GAS CHAMBER

In order to determine whether the mechanical properties of welds were affected by contamination with the atmosphere, welding tests were made in a special chamber, as shown in Figs. 13 and 14. The sides of the chamber were constructed of soft rubber so that the chamber could be collapsed. In the operation of the welding tests within the chamber, the plate material, the welding torch and the filler wire were placed inside the chamber as shown in Fig. 13. The chamber was collapsed as far as possible and then helium gas was introduced, which, by its own pressure, raised the top of the chamber to its fully inflated position. The gas pressure was then released and the chamber was again compressed or collapsed and the operation repeated five times. By this purging method the air which was originally in the chamber was diluted to a point where any residual air remaining was of a negligible factor. During the welding operation within the chamber, the usual gas flow was maintained in the torch, which was approximately 8 lpm.

Welding tests with alloy Ti-XCM in the chamber indicated a marked improvement in the performance of the arc

Fig. 13 Inside view of the special chamber as shown in Fig. 14

Fig. 14 Special chamber for welding in complete protection with helium gas

within the chamber. It was apparent that the stabilization of the arc was materially improved and that the maintenance of the arc for a definite arc length was easily performed. The weld metal also was completely free from oxide and was bright and shiny, having a polished lustrous surface.

In the original welding tests in this chamber using Ti-XCM, a fusion of only the parent stock was made within the chamber to determine the ductility, as shown by bend specimens of the fused plate material when welded under the most ideal conditions with respect to atmospheric contamination.

This test was made in order to determine whether the lack of ductility, which was encountered, was due to atmospheric contamination or to the added filler metal. By making this test under the ideal condition in which no filler metal is added and in which the atmospheric gases of oxygen and nitrogen were excluded, it was possible to evaluate the welding operation by eliminating these factors.

Bend tests were made of the fused plate material in the as-welded condition and after heat treatment. These are shown in Fig. 15. The left-hand side of the bend specimen was tested in the as-welded condition and revealed no elongation. The right-hand section of the same weld after the special heat treatment of 1350° F for 30 min, followed by furnace cooling to 1150° F, followed by water quenching, indicated a marked improvement in ductility, as shown by the extent of bending. A bend angle of 20 deg and elongation of 16% in $^1/_2$-in. gage length was obtained.

These tests have rather conclusively demonstrated that the ductility of the fused metal could only be obtained by heat treatment and that in the as-deposited or as-welded condition the brittleness encountered is primarily due to structure and possibly a stress condition.

A weld test plate was made within the chamber, of Ti-XCM alloy, using filler metal as strips removed from the parent stock and using a welding procedure described previously. This weld was given the special heat treatment of 1350° F for $^1/_2$ hr followed by furnace cooling to 1150° F and then water quenching. An all-weld tensile specimen of 0.357 in. diam was removed and tested with the results as shown in Fig. 16.

Figure 15

Test No. 44806. Type of plate: $^1/_2$-in. thick Ti-XCM alloy. Bend specimen representing surface fusion weld (no filler metal added) made with Heliarc torch in chamber filled with helium gas. As-welded condition: No bend ductility. The portion at right which was heat treated at 1350° F for 30 min, furnace cooled to 1150° F and water quenched, was bent to a 20-deg angle, resulting in 16.0% elongation in $^1/_2$-in. gage lines. A slight tear occurred along one of the dendrites for which reason the bending was stopped.

Figure 16

Test No. 44809. 0.357-in. diam., all-weld tensile. Type of plate: $^1/_2$-in. thick Ti-XCM. Type of filler: Strips of Ti-XCM plate. Condition: Heated at 1350° F for 30 min, furnace cool to 1150° F and water quench. Yield strength: 110,100 psi. Tensile strength: 118,900 psi. Elongation in 1.4 in.: 11.4%. Reduction of area: 16.9%.

The tensile test revealed uniform stretching over the entire reduced section with an elongation of 11.4% in 1.4-in. gage length. Tensile strength of

Table 7—Chemical Compositions of Commercial Titanium Alloys (Plate Material)

Type of alloy	*Alloying elements, %*								
	C	*Mn*	*Si*	*Cr*	*Fe*	*Al*	*Ti*	*W*	N_2
Ti-150A	0.02	0.0	0.002	2.46	1.03	0.20	95.05	0.058	0.017
RC-130A	0.16	6.04	0.002	0.04	0.43	0.38	92.26	0.22	0.030
RC-130B	0.13	3.46	Nil	0.02	0.25	3.42	92.45	0.023	0.031
Ti – 7% Mn	0.01	4.92	Nil	0.08	0.25	0.17	94.26	0.095	0.026
Ti – 4% Cr – 2% Fe	0.01	0.20	0.011	3.56	1.42	0.40	94.06	0.82	0.030
Ti-XCM	..	Trace	0.05	3.64	0.17	..	94.17	..	0.027

Table 8—Chemical Composition of Titanium Alloys Weld Metal

Type of weld	Alloying elements, % C	Mn	Si	Cr	Fe	Al	Ti	W	N_2
Ti-150A	0 02	0 07	0 019	0 25	0 98	0 35	96 71	0 16	0 055
RC-130A	0 15	5 54	0 021	0 03	0 31	0 13	93 65	0 027	0 058
RC-130B	0 15	3 25	0 007	0 01	0 29	3 45	95 69	0 08	0 059
Ti–7% Mn	0 01	4 68	0 026	0 01	0 28	0 11	94 65	0 12	0 085
Ti–4% Cr–2% Fe	0 02	0 14	0 009	3 12	1 80		93 32	0 82	0 054

118,900 psi was obtained with 16.9% reduction of area. These tests indicate that the special heat treatment has confirmed the results obtained with the simple fusion tests described above and that excellent ductility can be obtained.

While welding in a chamber has materially improved the arc manipulation and stabilization of the arc, it was not solely responsible for the increase in the ductility of the weld metal.

CHEMICAL ANALYSIS OF THE COMMERCIAL TITANIUM ALLOY PLATE MATERIAL AND WELD METAL

The chemical analyses were determined on the commercial titanium alloy plate materials and are shown in Table 7. These determinations were made in the A. O. Smith laboratory according to the latest approved chemical methods of analysis for titanium. This table shows the analysis of the commercial alloys with respect to the principal alloying elements and residual elements found. The chemical analysis of titanium alloy weld metal is shown in Table 8. The table shows an increase in the nitrogen content of the weld metal compared to the nitrogen content of the titanium stock. The analyses were made on welds made with the standard procedure without the use of the special chamber.

Tests are in progress to compare the effect of welding in a closed chamber of the other titanium alloys and to compare the results after heat treatments with those made in open air. The effect of the various types of heat treatments on the various titanium alloy weld metal are also under investigation to determine whether improvement in ductility can be obtained in those alloys.

SUMMARY

The results of the preliminary investigation carried out so far have indicated that tensile strengths equivalent to the parent stock can be obtained in a number of the alloys which were used in the tests.

Tensile strengths of 150,000 psi can be readily obtained. The investigation also indicated that postwelding heat treatment has a marked effect on ductility and notch toughness of the titanium alloy welds. The results of the radiographic examinations have also disclosed that the welding procedures, which were developed and used, were entirely satisfactory, in that sound weld metal can be produced in a commercial manner.

The tests have indicated that the commercial fabrication by welding of these alloys may be feasible and that the properties of the weld metal will depend to a large extent on the heat treatment and the type of alloys which are used. It is anticipated that as further investigations are carried out and also as improved new alloys are developed improvements in the mechanical properties of the weld metal can be expected.

We would like to acknowledge the helpful suggestions and assistance given by the technical staff of the Watertown Arsenal in carrying out this investigation and their permission for the publication of this research work.

Embrittlement of High-Strength Ferritic Welds

Discussion by Hallock C. Campbell and Richard P. Wentworth

An excellent paper has again been contributed by the Naval Research Laboratory. The authors write with the authority which stems from the great amount of work they have done in this field.

There was some discussion of the critical temperature Ac_1 of the NiMoV weld metal when this paper was presented in Philadelphia. We expressed the opinion that the value quoted by Puzak and Pellini is surprisingly low. In our work[1] we show no indication of austenitization on holding specimens at 1300° F for 18 hr. Puzak and Pellini show some austenitization at 1250° F. Normally, one would turn to the TTT diagram[2] to answer such a question, but unfortunately the investigation made by the Naval Research Laboratory for the Welding Research Council determined only the Ac_1 temperature, which was 1450° F. Admittedly Ac_1 is above Ac_1, but we questioned whether it should be as much as 200° above. In reply to this query Mr. Pellini pointed out that very rapid heating and cooling rates were used in the Welding Research

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Paper by P. P. Puzak and W. S. Pellini was published in THE WELDING JOURNAL, 31 (11), Research Suppl., 521-s to 526-s (1952).

Council investigation in order to simulate the conditions encountered in welding. He consequently felt that the Ae_1 temperature was in truth far below the reported Ac_1 temperature. In his written discussion of our paper Mr. Pellini further points out that the formation of austenite at 1250° F has been confirmed at NRL by dilatometric tests.

In rebuttal we call attention to the fact that a completely ductile fracture and good contraction beneath the notch are obtained with the notch-bend specimen after long holding times at 1300° F. Thus no austenite would seem to have formed in our specimens at this temperature. Pending further work by both laboratories, we therefore must agree with Puzak and Pellini that there is a major disagreement in the conclusions of our two tests on this point.

There is better agreement in regard to transition temperatures, as shown by the following table obtained from various sources in the literature.[3–5] Both stress-relieved and as-welded values are shown.

15 Ft-Lb Charpy Impact Strength

	Puzak and Pellini V-notch	*Smith and Rinehart[3] Keyhole*	*Bibber, et al.[4] Keyhole*	*Campbell[5] V-notch*
120,000 psi NiMoV				
As-welded, ° F	−100	−80	−60	...
Stress relieved, ° F	+30	....	+130	...
100,000 psi MnMo				
As-welded, ° F	−80	Below −80	−172*	−80
Stress relieved, ° F	−100	Below −80	−99	−40

* Ductility transition temperature.

Unfortunately some of the above data are V-notch and others are keyhole notch. In general, V-notch data are expected to indicate a higher transition temperature than keyhole specimens, which means the NiMoV data of Puzak and Pellini do not agree too well with those of Bibber, *et al.*[4] On the other hand, the keyhole notch might explain the much lower value of Bibber's MnMo sample. Even so, our feeling is that the −172° F figure of Bibber is too good, and that the NRL value of −80° F is more typical. In the Philadelphia discussion Dr. Doty described the shape of the transition curve obtained by U. S. Steel for the MnMo electrode. Their curve exhibited an extensive plateau at 16 ft-lb separating the ductility and fracture transitions. The center of the ductility transition scatter band was at −172° F, as reported.

Attention is called to these published references to the performance of NiMoV and MnMo weld metal, because all observers have agreed that both electrodes are of excellent notch toughness as-welded, and in the case of the MnMo electrode no one has shown any adverse affect of tempering treatments.

Regarding Pellini and Puzak's comments on our presentation of the bend test data, the "ductile" label on the 1200 to 1250° F range of our Fig. 3 is not to be divorced from the fracture appearance symbols and the percent contraction values. Full recovery at 1200° F was achieved only in so far as the ductility equalled or bettered that obtained in the as-welded condition. The ductility exhibited by the bend specimens after tempering at 1200° F does not approach that obtained after tempering at 1250 or 1300° F.

We agree with the authors that the recommendations of both our paper and theirs must be considered carefully from the standpoint of the steel to be welded. If the weld must meet specification MIL-E-986A, the NiMoV electrode is not suitable, for the loss in strength for the Class 260 electrode is some 20,000 psi at 1250° F, which would drop this electrode into Class 230. There are some applications, however, in which such a performance still is acceptable. An outstanding property of the Ni-Mo-V grade is its ability to weld without preheat. This has been of great interest to fabricators of large equipment made with low-alloy high-tensile steel. If, in certain cases, preheating is found to be necessary, the NiMoV electrodes usually require 100 to 200° F lower preheat than the MnMo electrodes. This is attributed to the lower carbon content of the NiMoV electrodes. There is also a need to weld certain cast steels used for fabrication of land vehicles, which are customarily heat treated after welding. We did not attempt to consider the base metal in our paper, but only tried to find a beneficial heat treatment for the weld metal.

The use of the 100,000-psi NiMoV grade for welds that required stress-relieving treatments should, we believe, receive more consideration and investigation. The notch toughness of this grade is considerably higher in the brittle range (1000–1150° F) than the 120,000 grade and for many applications would probably be quite satisfactory if stress relieved in this range. The as-welded strength might at the same time be increased after the stress-relieving heat treatments to satisfactory levels. If the as-welded tensile strength was 110,000 psi, an 1150° F treatment would probably increase it to 120,000 psi.

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The Influence of Corrosion on the Cracking of Pressure Vessels

This report makes particular reference to stress corrosion and corrosion fatigue. It has been prepared under the sponsorship of the Materials Division, Pressure Vessel Research Committee, Welding Research Council

by H. R. Copson

SUMMARY

CORROSION will not produce cracking unless it is combined in some way with stress. The most serious damage occurs when stress and corrosion combine to produce certain mutually accelerating effects. This may take the form of what is called stress corrosion cracking, involving static tensile stresses, or corrosion fatigue, involving cyclic stresses.

Corrosion can combine with stress to produce less spectacular damage. Local corrosive attack produces stress concentrations at the notches, pits and grooves which may be formed, and this ultimately can lead to cracking at the weakened positions. If corrosion takes the form of intergranular attack, tensile stresses such as exist in pressure vessels would tend to open up the metal and keep the attack going, and thus ultimately lead to cracking.

It should not be inferred that stress always increases corrosion. In the absence of cracking, experience indicates that the effects of normal amounts of static stress on general corrosion are small. No recognized problems exist in this connection.

In certain circumstances corrosion can produce another type of damage which is associated with charging the metal with hydrogen. The hydrogen can produce embrittlement, blistering or fissuring, and thus seriously weaken the metal.

The effects of corrosion on pressure vessels may often be minimized by intelligent design, by reduction where possible in internal or applied stresses, and by choice of materials suitably resistant to their expected service environment. Control of the environment itself, by dilution or lowering its temperature is sometimes practical, and inhibitors are effective in certain instances. Paints and protective coatings, and cathodic protection or use of sacrificial anodes are sometimes employed.

Many of the factors involved in the corrosion of pressure vessels require clarification and could well be the subject of profitable research. A great deal of work along these lines is being actively pursued and it is significant that about half of the literature references were published within the past five years.

FORMS OF CORROSION

If corrosion were a uniform wasting away of the surface, it could easily be provided for by the design engineer and would present no difficult problems in pressure vessels. Corrosion, however, takes many different forms. The forms might be classed as uniform attack, local attack, galvanic attack, corrosion cracking, corrosion-erosion and subsurface attack at high temperatures.

Uniform attack is a general wasting away of the surface such as might occur in acids, or in many other solutions or as high temperature oxidation. It is easily expressed as a uniform corrosion rate in milligrams per square decimeter per day or in inches per year. Likewise it is easily taken care of in pressure vessels by allowing enough extra thickness to take care of the expected corrosion damage during the life of the equipment. Sometimes, uniform attack is not obvious in that the corrosion products may remain in place, and the dimensions and superficial appearance of the material may not change. This occurs in the so-called graphitic corrosion of cast iron where the metal is destroyed but the graphite is left intact.[1] It may also occur in the dezincification of brass alloys where the zinc is removed and a porous layer of copper is left behind.[2] In either case the structure would have lost greatly in strength without this being readily apparent.

Unfortunately corrosion is not always uniform but frequently shows a tendency to localize, with the attack

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occurring in critical locations or as scattered pitting. Such local attack might be caused by differential aeration cells,[3] by concentration cells[4] or by impingement attack.[5] It might occur at breaks in scale, under deposits or in crevices.[6] Pitting, of course, is more damaging than the same weight loss spread uniformly over the surface. Pitting causes concentration of stresses at the root of the pit, and this can be particularly bad where the pits line up in rows or where the local attack forms grooves and notches.

Galvanic corrosion occurs when a current flows between dissimilar metals in contact in a conducting electrolyte.[7] It is of interest in pressure vessels primarily where it may cause deep local attack. This might occur where the anodic member of the couple has a relatively small area or where the conductivity of the liquid is insufficient to spread the galvanic corrosion over an appreciable area. If, for any reason, the current density is low, the galvanic corrosion will not be serious.

The term corrosion cracking includes all the instances where corrosion is associated with cracking. These have already been outlined and are considered in detail below. The main forms are stress-corrosion cracking and corrosion fatigue, but local attack, intergranular attack and hydrogen embrittlement may lead to cracking under suitable conditions.

Corrosion-erosion involves those conditions where erosion and corrosion go hand in hand[8] as can occur in pressure vessels subject to high velocity flow at an inlet. Removal of protective corrosion products by erosion allows the metal to continue to deteriorate at its initially rapid rate. Local impingement attack can form small bare areas which are anodic to adjacent filmed areas, and thus lead to rapid local corrosion and pitting. Cavitation erosion, fretting corrosion and wire drawing all involve both erosion and corrosion. While some form of corrosion-erosion might show up in pressure vessels, it generally does not lead directly to cracking.

Corrosion at high temperatures sometimes causes another form of attack, namely damage beneath the surface. This might take the form of internal oxidation, of carburization, of sulfidation, or of some combination of these. Hydrogen under pressure may cause decarburization and the development of voids and fissures.[8] It is obvious that such subsurface attack can seriously weaken and embrittle the metal. It must be considered in pressure vessels operating at high temperatures.

It is evident that the various forms of corrosion overlap and are not always sharply defined. Several forms of attack may be present simultaneously. The field is large and complicated with many ramifications. Consultation with experienced corrosion engineers is usually desirable in the analysis of a particular failure. In the design of new equipment close cooperation between the design engineer and the corrosion engineer is well warranted and are often highly essential.

CORROSION FROM A DESIGN VIEWPOINT

From a corrosion standpoint, suitable materials can sometimes be chosen on the basis of prior knowledge and experience.[3,9–11] More often, and particularly when new processes or environments are involved, corrosion tests are required.[12–14] For best results the tests should be made under actual operating conditions, although the variables involved can often be studied to advantage under controlled conditions in the laboratory. Since corrosion behavior is altered in manifold ways, it is not wise to cut corners in corrosion testing. No safe short cuts or accelerated tests are known.

For example, to simulate corrosive conditions in a pressure vessel operating at the boiling point, it might seem logical to conduct immersion tests in the boiling liquid. However, if heat is being applied from the outside, the skin temperature of the metal may be appreciably higher than that of the liquid. This hot wall effect has been known to greatly accelerate and localize corrosion. Numerous illustrations of this sort could be cited. The point is that unless the service conditions are reproduced in all their ramifications, the whole story may not be brought out, and the results may even be misleading.

Reliance should not be placed entirely on weight losses or inches penetration per year. It should be known if the strength of the material has been damaged, as by intergranular corrosion, local attack or pitting. It is helpful if there is supplementary information, involving changes in corrosion rates with time, the effects of relative velocity between the metal and its corrosive environment, and the effect of static or cyclic stresses.

Once the corrosion picture has been explored and suitable materials have been selected, design becomes an important factor in preventing and minimizing corrosion. For example, if corrosion is greatest near the liquid line, it may be possible to provide extra metal thickness in this vicinity. If corrosion is greater near one end of a pressure vessel it may be practicable to design the vessel so that it can be turned end for end. If there is increasing corrosion near the entrance end of heat exchanger tubing, it may be possible to insert short replaceable inserts in the ends. Corrosion can often be minimized by frequent cleaning and by controlling moisture and oxygen.

The design should be such as to facilitate replacement of parts subject to corrosion. If practicable such parts should be interchangeable. The equipment should be designed for complete drainage and easy cleaning. Exceeding normal capacity should be avoided. Galvanic effects between dissimilar metals should be avoided.[15] Impingement, turbulence, localized heating, stagnant areas, crevices and stress concentration should be avoided. A number of authors have considered the influence of design in greater detail.[16–19]

STRESS CORROSION CRACKING

Stress corrosion cracking is something which the design engineer should always keep in mind in specifying materials, particularly in the case of pressure vessels. The presence of internal stress should always be taken into account when deciding the magnitude of externally applied stresses to which the equipment can be safely subjected. Unfortunately there are no guiding rules which can be followed. About all that can be said is that stress corrosion cracking is specific both for the metal and for the environment. In certain special environments the presence of tensile stresses may lead to the cracking of certain metals. With other environments or with other metals or alloys no difficulty is encountered. Reliance must be placed on practical experience or on laboratory or field tests.

The term stress corrosion cracking is used to indicate the combined action of static tensile stress and corrosion which leads to cracking. The principal factors are the magnitude of the stress, the nature of the environment, the length of time involved and the internal structure of the alloy. These factors are not independent, but interact, one accelerating the action of another. Their relative importance varies with conditions.

If stress corrosion cracking is to occur there must be tensile stresses at the surface. The stresses may be internal or applied, the two types being additive. Examples of internal stresses are those produced by deformation during cold work, by unequal cooling from high temperature and by internal structural rearrangements involving volume changes. Stresses induced when a piece is deformed, those induced by press and shrink fits and those near welds, rivets and bolts may be classed as internal stresses.

In many cases these concealed stresses are of greater importance than actual operating stresses. This is true also of pressure vessels, except perhaps for those operating at loads which are high in relation to the strength of the material. When the factor of safety required in design is considered, operating stresses are generally low enough to be of comparatively little importance, except as they add to the internal stresses.

The actual stresses may vary greatly from point to point within the metal, and in some locations are much higher than the average value. A nonuniform stress distribution is expected, nevertheless a high localized stress is considered more damaging than a uniform load. Generally tensile stresses in the neighborhood of the yield strength are present in stress corrosion cracking failures, but failures are known which have occurred at much lower stresses. In any case the stress levels are low enough so that normally a great deal of general corrosion could be tolerated. The interaction of the stress and corrosion produces cracking where it would not otherwise be expected.

Stress corrosion cracking has been observed in almost all metal systems. Yet for each metal specific environments are required to produce it. No stress corrosion cracking has occurred in a vacuum. The environment that induces cracking frequently attacks the metal only superficially if stresses are absent. Many of the environments that cause cracking tend to produce a pitting type of corrosion.

One of the curious aspects of stress corrosion cracking is the wide difference in time required for failure, which varies from a matter of minutes to many years. Associated with this is the probability of cracking. Specimens which are apparently similar may not behave alike, with perhaps 40% cracking in a short time, and the rest remaining uncracked for a much longer time. Laboratory tests require severe conditions to produce cracking in reasonable time, whereas in service much milder conditions may cause cracking in the longer time available.

Considerable time may be required before corrosion proceeds to the extent that it begins to be accelerated by the tensile stresses present. The more severe the corrosive conditions and the higher the stress level the sooner this will happen. With some alloys there is an incubation period, during which precipitation or other structural changes may be occurring. For example, aluminum-magnesium alloys (over 6% magnesium), immediately after heat treatment, may not show any susceptibility to cracking in accelerated laboratory tests, but after aging at room temperature for 6 months, stress corrosion cracks may form rapidly in the same test.

As just indicated the internal structure of the metal or alloy can be of considerable importance. The internal structure is dependent upon composition, upon the method of fabrication and whether the metal is as-cast, hot worked or cold worked. It is also dependent on thermal treatments and the extent of natural aging.

There have been numerous reviews and books on stresse orrosion cracking.[9, 20–24] There is also a voluminous literature. This should be consulted for detailed information. The more important instances of stress corrosion cracking are discussed below.

Caustic Embrittlement

A well-known example of stress corrosion cracking is the caustic embrittlement of steel in steam boilers.[25] The cracking is associated with the presence of sodium hydroxide in the boiler and hence the name caustic embrittlement. The metal away from the cracks, however, is ductile and not brittle. When a boiler lets go because of caustic embrittlement, results can be disastrous as illustrated in Fig. 1.[26] Other examples of severe explosions have been cited by Zapffe.[27]

The cracking is said usually to be predominantly intercrystalline, and Fig. 2 is an illustration of this. This photomicrograph was prepared from the steel of an autoclave exposed to 50% caustic soda at 250° F and 400 psi. This is perhaps a more concentrated solution than normally encountered in steam boilers, but it is an excellent example of caustic embrittlement just the same. Oxides are present in the cracks, which

Fig. 1 Power plant after explosion due to caustic embrittlement of steam boiler[26]

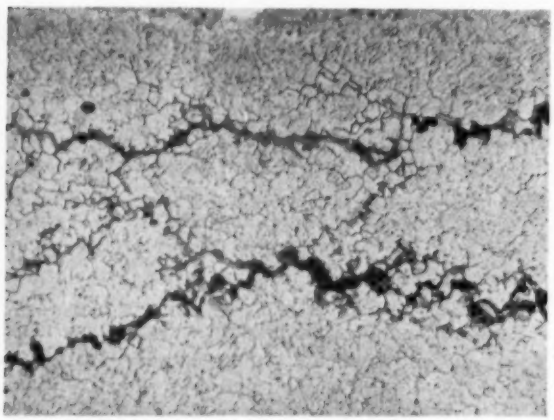

Fig. 2 Caustic embrittlement of steel exposed to 50% caustic soda at 250° F. 250 ×

is typical. In other cases the cracks may be partly transcrystalline, or even, as illustrated in Fig. 5, predominantly transcrystalline. It used to be thought that stress corrosion cracks were characteristically intergranular, but many cases are now known where the cracking follows a path across the grains.

In steam boilers the caustic present concentrates at small leaks or capillary spaces. The caustic concentration builds up to high values at such places. High tensile stresses must be present, of course, and usually the cracking takes place along rows of rivets where there may be slight leaks. Salt deposits have been observed in some cracked rivet seams.

In laboratory tests a U-bend specimen with a bolt through the legs is convenient for studying caustic embrittlement. Specimens of this nature are shown in Fig. 3. The U-bend specimen has tensile stresses in the outer fibers in the neighborhood of the yield point, and high stress gradients such as frequently occur in practice. Any cracking is located on the outside of the bend as shown in the figure. The white material in the cracks is residual caustic. These steel specimens were exposed to boiling 33% sodium hydroxide containing 0.1% lead oxide for 14 days.

U-bend specimens of this type were used by Berk and Waldeck[28] to outline dangerous concentrations and temperatures of caustic. They obtained no cracking in 30 days or longer at concentrations below 15% or above 43% or at temperatures below 180° F. However, under long-time service conditions, cracking has been observed well outside these limits.[29] Also it is known that constituents present in small amounts may act as accelerators or as inhibitors of the cracking.

In laboratory tests it is difficult to obtain consistent behavior in pure caustic. Cracking is readily produced by adding certain oxidizing agents or accelerators. Thus cracking in boiling 33% sodium hydroxide can

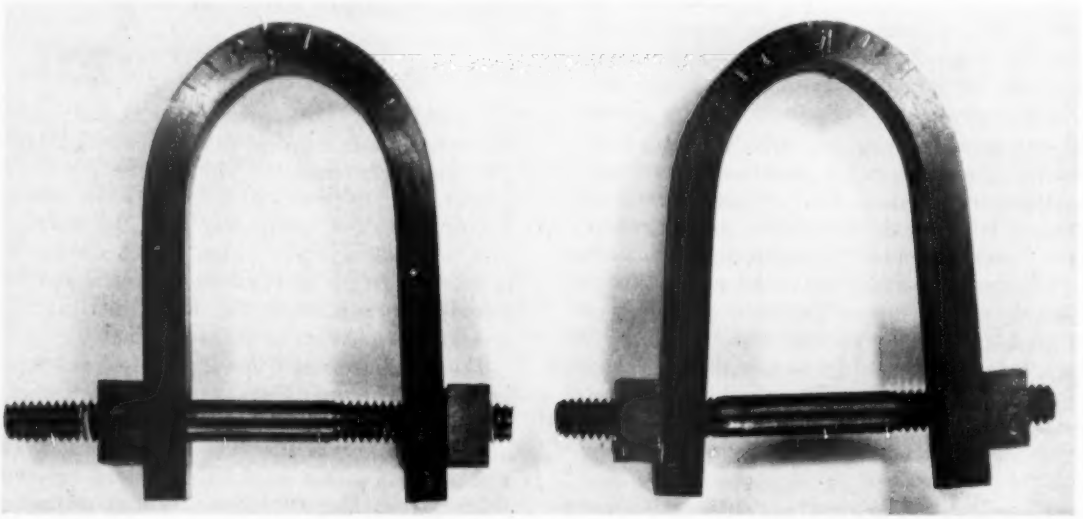

Fig. 3 Steel U-bend specimens after exposure for 14 days to boiling 33% sodium hydroxide containing 0.1% lead oxide. Natural size

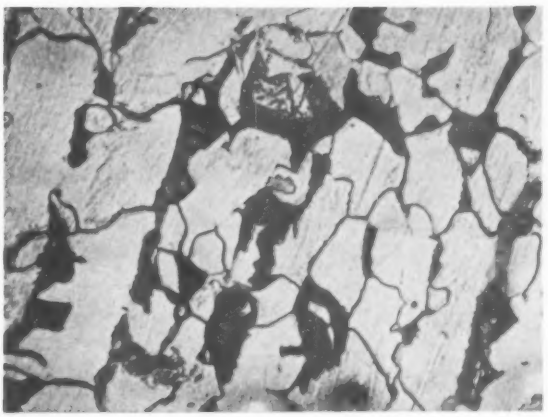

Fig. 4 Intercrystalline cracking of steel U-bend specimens after 15 days in boiling 33% sodium hydroxide containing 0.1% lead oxide. 500 ×

be consistently obtained by the addition of 0.1% lead oxide. Figure 4 illustrates the intergranular nature of the cracking in steel U-bend specimens exposed to this media. Cracking can also be consistently obtained under similar conditions by the addition of 0.3% sodium silicate. Figure 5 shows that under these slightly altered conditions the cracking was transcrystalline. Figures 4 and 5 are for the same steel and practically identical conditions except for the change in minor constituents in the caustic. Other stress corrosion cracking systems are known where slight changes in conditions have changed the path of the cracking. This fact is not explained by some of the theories of stress corrosion cracking.

Under service conditions caustic embrittlement is sometimes avoided by adding inhibitors of the cracking to the water. Thus tannins, lignins, quebracho extract, waste sulfite liquor, sodium nitrate, sodium phosphate and other additives have been beneficial in some cases.

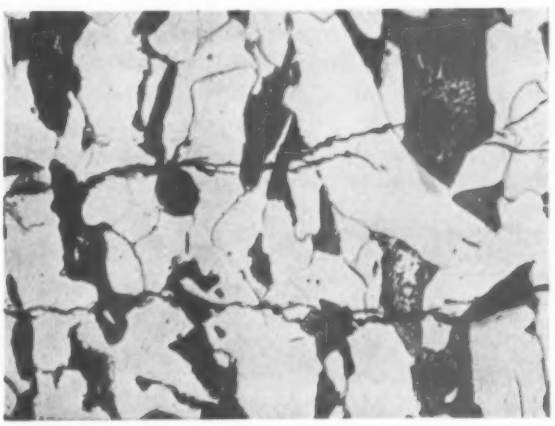

Fig. 5 Transcrystalline cracking of steel U-bend specimens after 12 days in 33% sodium hydroxide containing 0.3% sodium silicate at 300° F. Same steel as Fig. 4. 500 ×

An embrittlement detector has been devised which can be attached directly to a pressure vessel to determine whether or not the water is capable of producing caustic embrittlement.[30] The detector has a base which consists of a rectangular block with a hole through which the water circulates. The test specimen is clamped to this base. It is bent and maintained under stress by means of an adjusting screw which passes through the specimen and presses against this base block. A small hole conducts the water from the base block to the contact surface between the base and the specimen. By correct setting of the clamping nuts and adjusting screw a very slow leak of steam is established. Thus a concentrated solution forms under the bent area of the specimen. If the water is embrittling and sufficient time is allowed, such as 30 days or more, the specimen will crack. If the water is not embrittling no cracking will occur.

All steels are not equally susceptible to caustic embrittlement. Deoxidation practice and the residual elements present have some effect. However, the improvements have been minor and no steel has been devised which is completely resistant. Low-alloy steels crack as readily as plain mild steel.[27, 29]

A welded construction is sometimes recommended as being superior to a riveted construction, the argument being that this should prevent the concentration of caustic at leaks and capillary spaces. Welds are apt to introduce high internal stresses, however, and welded pressure vessels have failed by caustic embrittlement.[31] As-welded steel tanks are recommended for caustic service up to 140° F, but for higher temperatures welded tanks must be stress relieved.[29] A low-temperature stress relief of welds has been proposed.[32] This consists of heating a narrow band each side of the weld to 350–400° F and quenching. This produces localized stretching with a resultant decrease in stress. Of course, where practical, a full stress relief anneal of the entire vessel is far safer.

Nickel cladding has been used successfully to prevent caustic embrittlement. Where the clad areas are joined by welding care must be taken to insure sound welds. The cracking illustrated in Fig. 2 was in an autoclave lined with nickel. The welds were defective and allowed the caustic to contact the steel with the result that cracking of the steel occurred.

Lowering the tensile stresses present when possible is a standard means of preventing caustic embrittlement. This and other means of preventing stress corrosion cracking are considered further below.

Stress Corrosion Cracking of Iron

In addition to caustic embrittlement, iron and steel alloys are subject to rapid stress corrosion cracking in some nitrate solutions.[33] Cracking has occurred in concentrated calcium nitrate and concentrated ammonium nitrate. Highly stressed bridge cable wire cracked in dilute ammonium nitrate and in dilute so-

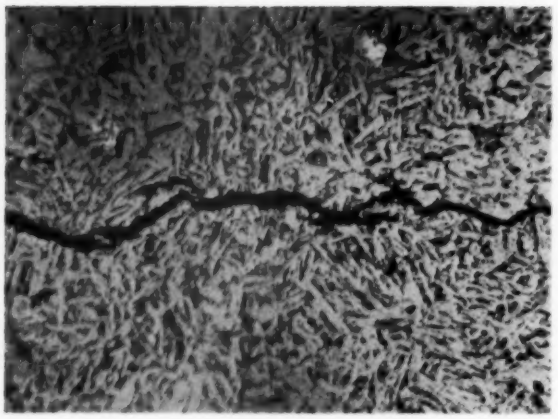

Fig. 6 Transcrystalline cracking of steel U-bend specimens exposed for 6 days to water saturated with a 50:50 mixture of hydrogen sulfide and carbon dioxide at 100° F.[38] 500 ×

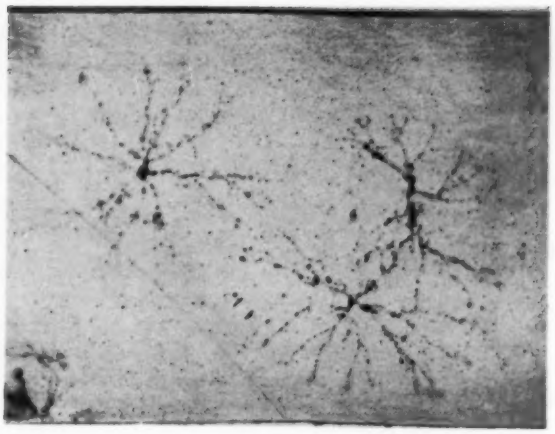

Fig. 8 Stress corrosion cracking of stainless steel kettle handling a baked bean sauce high in chlorides. Natural size

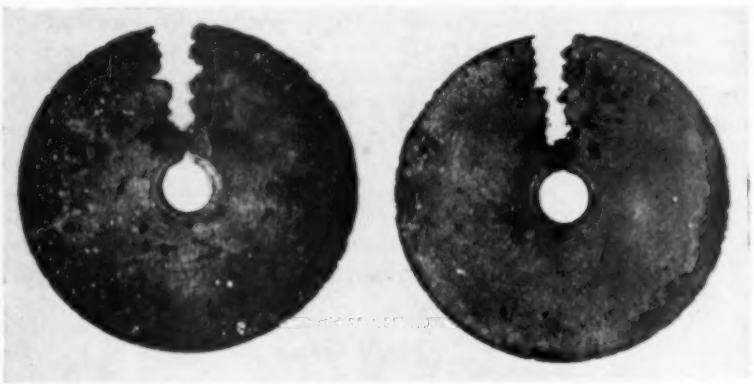

Fig. 7 Stress corrosion cracking of stainless steel around stenciled identification marks and at machined edges. The specimens were exposed in 12% hydrofluoric acid containing 0.2% fluosilicic acid. Natural size

dium nitrate, but not in distilled water, dilute ammonium sulfate, ammonium nitrite or sodium hydroxide.[34] Cracking has occurred in concentrated nitric acid and also in dilute nitric acid containing manganese dichloride as an accelerator.[35] All these failures were largely intergranular.

Transcrystalline cracking has been observed in tanks holding certain gases under pressure. This has been attributed to moisture and traces of hydrogen cyanide,[36] and to moisture and traces of hydrogen sulfide.[37] Figure 6 shows the transcrystalline cracking of steel U-bend specimens exposed for 6 days to water at 100° F saturated with a 50:50 mixture of hydrogen sulfide and carbon dioxide.[38] Embrittlement by hydrogen may be involved in this cracking. Cracking of similar nature has occurred in high-pressure gas condensate wells containing hydrogen sulfide and carbon dioxide.[39] Ammonium thiocyanate seemed important in the stress corrosion cracking of steel gas mains.[40] Undoubtedly additional corrosives which cause stress corrosion cracking of steel will come to light. This should be considered in exposures involving new chemicals.

Stainless Steel

Figure 7 shows an instance of stress corrosion cracking of Type 302 stainless steel. Disk-shaped specimens were immersed for 7 days in a solution containing 12% hydrofluoric acid and 0.2% fluosilicic acid at 182° F. Cracks formed around stenciled identification marks causing these sections of the specimens to fall away completely. Cracks can also be seen at the machined edges.

Figure 8 shows another instance of stress-corrosion cracking, this time of a Type 304 stainless steel kettle handling a baked bean sauce which was high in chlorides. The cracks had a radiating pattern and tended to line up with small sharp pits.

Stress corrosion cracks in stainless steel are usually transcrystalline. A typical example is shown in Fig. 9. These cracks occurred in a specimen exposed to a boiling calcium-magnesium chloride brine. Intergranular cracking has been observed, but only when the heat

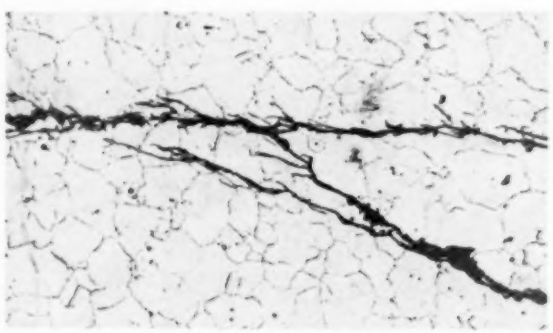

Fig. 9 Transcrystalline nature of the stress corrosion cracking of stainless steel. 100 ×

treatment has been such as to make the stainless steel susceptible to general intergranular corrosion.

The stresses required to cause cracking in the stainless steels sometimes seem comparatively low, a stress of less than 20,000 psi being reported sufficient by Scheil in one instance.[23] Some Type 347 tubing was found to be susceptible to cracking in boiling calcium magnesium chloride brine after stress-relief annealing from 1350° F, but resistant to cracking after a slow cool from 1600° F. Slow cooling is essential as quenching stresses may be sufficient to cause cracking.

Ferritic stainless steels are less susceptible to stress corrosion cracking than the austenitic alloys. Generally, cracking cannot be avoided by shifting from one austenitic grade to another, although there may be real differences in behavior, with increased corrosion resistance and increased austenitic stability being helpful.[41]

A thorough review of environments causing stress corrosion cracking of stainless steels was prepared recently by Nathorst.[42] The number of environments seems large, but in spite of this the austenitic chromium nickel stainless steels perform satisfactorily under many service conditions.

Most cases of cracking involve the presence of chloride ions, particularly if the solution is acid. Hot concentrated solutions of chlorides of magnesium, calcium, barium, cobalt, zinc, lithium, ammonium and sodium all cause rapid cracking.[43] Cooler or more dilute solutions may be satisfactory. Organic chlorides, such as ethyl chloride, which decompose in the presence of moisture to form hydrochloric acid may cause cracking.[44]

In many cases where some other environment was thought to cause cracking, closer investigation has shown that chlorides were actually present, even if only as an impurity. Thus cracking has been reported in sulfite waste liquors of the cellulose industry, but in almost every case brackish waters were used. Likewise cracking has been reported in steam and hot water, but in such cases it appears that the design is such as to allow local concentrations of chlorides.

Stainless steels are susceptible to stress corrosion cracking in hot concentrated caustic solutions. The presence of sodium sulfide and reducing substances is said to increase the danger of cracking in caustic. Rees has reported cracking in moist hydrogen sulfide.[24] Cracking has also been reported in some other environments.[42]

Copper Alloys

Perhaps the best known example of stress corrosion cracking in copper alloys is the season cracking of brass,[45–47] so-called because the cracks resemble those in seasoned wood. Exposure to moist ammoniacal atmospheres is believed to be necessary to produce the cracking, but oxygen and carbon dioxide have a contributing effect. Cracking is fast in contaminated atmospheres, but has occurred under apparently normal outdoor and indoor conditions. Evans has speculated on the role of ammonia in promoting the cracking.[24]

Susceptibility to cracking increases with tensile stress. Stresses of 12,000 to 20,000 psi readily cause cracking, but cracking is rare with stresses below 12,000 psi. Susceptibility to cracking increases greatly with zinc content. Alloys with 85 to 90% copper are practically immune, and with 90% copper they are fairly free from cracking. Two-phase brass compositions, such as 60 copper, 40 zinc, are more susceptible than alloys with less zinc. Special brasses which contain other elements behave similarly to the straight zinc brasses. The cracking is usually intergranular, but transcrystalline cracking has been reported, particularly in the beta phase of high zinc brasses.

As compared with the brasses, other commercial copper alloys, as aluminum bronze, tin bronze, silicon bronze and cupronickel show comparatively little tendency to season crack, although failures are known, and sometimes the failures may occur in other than ammoniacal atmospheres. For example, the ASME Boiler Code cautions on the use of silicon bronze in steam above 212° F. Cook[24] reported pure copper to be immune to cracking for all practical purposes. Thompson and Tracy[48] found most additions to copper to cause a rapid increase in susceptibility to cracking, but larger additions of the same elements caused the susceptibility to decrease again.

An acid mercury salt solution is sometimes used as an inspection test to determine the susceptibility of copper alloys to stress corrosion cracking.[29, 49–52] Metallic mercury is liberated on the surface and penetrates stressed metal intergranularly. This is a different type of attack than stress corrosion cracking, but results are roughly comparable. However, cracking in service has been known to occur in material which has passed the mercury test.

A better but more difficult test involves exposure to a gas phase containing ammonia, air, water vapor and carbon dioxide.[48, 49] This relates directly to service conditions. For reproducible results the temperature must be controlled and also the composition of the gas phase. With this test there seems to be no threshold stress below which cracking will not occur in time. This probably relates to the fact that some intergranular attack occurred in the absence of stress. This test is particularly suited for experimental studies.

Aluminum Alloys

Pure aluminum is quite resistant to stress corrosion cracking. On the other hand aluminum alloys containing more than 12% zinc or more than 6% magnesium have cracked in such mild environments as the atmosphere and tap water.[23, 53]

In aluminum alloys the cracking is intergranular. It is significant that grain boundary constituents have been observed microscopically, and that potential measurements have shown the grain boundary region to be anodic to the grains in solutions known to produce cracking. Attempts have been made to extend these observations to other alloy systems.[54]

In studying the stress-corrosion cracking of aluminum alloys it is customary to use salt solutions containing sodium chloride and hydrogen peroxide. Susceptible alloys crack rapidly under these conditions. Complete immersion, alternate immersion and spray have been used as well as anodic currents.

Magnesium Alloys

Pure magnesium, magnesium casting alloys and magnesium-manganese alloys are relatively resistant to stress-corrosion cracking. On the other hand some magnesium alloys will crack rapidly in the atmosphere and in a variety of corrosives.[55, 56] The sensitivity to cracking increases with aluminum and zinc content. Minor impurities such as iron may be bad. Additions of lead, tin or cadmium seem to have little effect.

In magnesium alloys the cracking is predominantly transcrystalline. Cold rolled and fully annealed materials are more sensitive than fully precipitated materials. On the more sensitive materials welding increases the possibility of cracking because of high stress and the presence of annealed areas adjacent to the weld. Riveted seams are less prone to cracking. Creep may relieve the stresses in wrought magnesium alloys, particularly those low in aluminum and zinc.

In studying the stress corrosion cracking of magnesium alloys, tests have been made in both inland and marine atmospheres, and in sodium chloride solutions with and without added chromate.[20] A wide variety of test specimens has been used.[23] Behavior varied somewhat with the conditions of test. Thus the salt chromate solution was said to correlate well with the exterior test, but not with tests in plain salt solution.

Other Metals and Alloys

Stressed metals are used satisfactorily in many environments. No way is known of predicting behavior in a new environment. A medium which produces cracking of a given alloy may have no effect on other alloys. Thus titanium seems to resist stress corrosion cracking under conditions where stainless steels have failed.[57]

Nickel and nickel alloys are comparatively immune to this disease, but Fraser has reported a number of failures.[23] Stressed Monel has been found to develop both intergranular and transcrystalline cracking in fluosilicic acid. In laboratory tests in moist vapor, U-bend specimens quickly develop transcrystalline cracking, Fig. 10.[38] Under service conditions the cracking has sometimes been intergranular, Fig. 11.

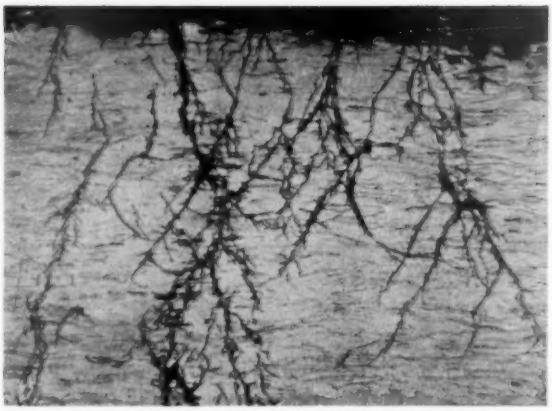

Fig. 10 Transcrystalline cracking of Monel U-bend specimens exposed to moist fluosilicic acid vapor for 10 days.[38] 100 ×

Lead under static tensile stress has been shown to crack intergranularly in lead acetate solution, but not in distilled water.[58] The impure zinc die castings used many years ago seemed susceptible to intergranular stress corrosion cracking.[9] It has been said that if the right environment were found, stress-corrosion cracking could be produced in all metals and alloys.

Molten Metals

Often associated with stress corrosion cracking is the attack of molten metals on stressed material.[58] This is not really stress corrosion cracking, because the attack can be classed as corrosion only by a liberal interpretation of the term. The mercury test for stressed brass is of this type. It seems to be the rule (possibly with exceptions) that there is danger of intergranular penetration by molten metal, provided tensile stresses are present and provided clean metal surfaces are exposed. Wetting of the surface, interfacial angles and intermetallic compounds may be involved.[59] Oxide coatings and other surface coatings may be protective. Bending test specimens while immersed in the molten metal is a good way of producing the attack. In the

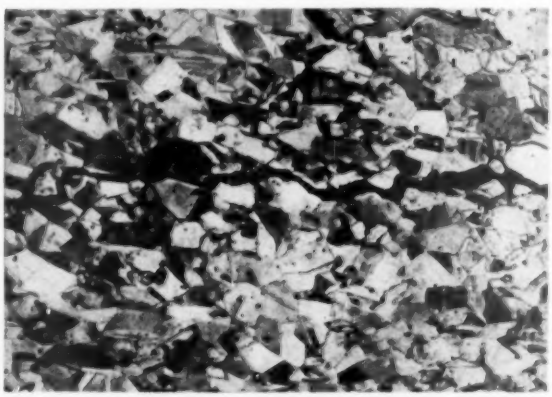

Fig. 11 Intergranular stress corrosion cracking of Monel in fluosilicic acid service. 100 ×

absence of tensile stresses the nature of any attack by molten metals will be general on the surface, instead of intergranular.

Tests for Stress-Corrosion Cracking

A number of tests have already been described. It is important to reproduce the service environment. The stress may be applied in numerous ways. A constant load applied directly, through a lever, or by means of a spring permits accurate measurement of the applied stress. Weights may be hung on specimens so as to produce bending, or the loading may be eccentric. To obtain stresses similar to those present under service conditions, constant deformation is sometimes preferred, with U-bends, C-bends, and modifications being used. Flattened tubes and welded specimens have also been used. With constant deformation, small cracks relieve the stress, and if many small cracks form, growth of cracks may cease. With constant load, cracks increase the stress on the remaining sound metal and hasten failure.

Internal stress may be estimated by mechanical, X-ray, or other methods.[60–62] With a suitable setup, applied tensile stress may be measured directly, or from stress-strain curves by means of extensometers or electric strain gages.[62] To avoid complications it may be preferable to start with stress-relieved material.[42]

Correlation between laboratory tests and service performance is difficult to obtain. Exact correlation should not be expected because service conditions are frequently complex. Failure in an accelerated laboratory test does not mean necessarily that failures are to be expected in practice. Experience has shown that generally stress corrosion cracking is not encountered in service unless the tensile stresses present (internal plus applied) are high. Laboratory tests are useful as a means of control, in developing new alloys, and in isolating the specific components of the environment responsible for the cracking.

Prevention of Stress-Corrosion Cracking

The obvious methods of prevention are either to remove the excessive tensile stress or to remove the corrosive. A full anneal and slow cool of the fabricated pressure vessel is a dependable means of preventing stress-corrosion cracking provided applied loads are not excessive. A full anneal is not always permissible because it lowers the properties. It has been found, however, that with suitable temperature and time the loss in strength and hardness can be minimized. An indication of such stress-relief annealing treatments is given in Table 1.[20, 47] The exact limits of time and temperature depend on the severity of deformation, the composition of the metal and the degree of softening allowable. Manufacturers should be consulted concerning specific alloys and service conditions. The heat treatment should be followed by slow cooling to safe temperature levels, and care should be taken to insure that no subsequent operation restores the internal stress.

Table 1—Suggested Stress Relief Annealing Treatments to Be Followed by Slow Cooling

Material	*General range of temperature, ° F**	*Holding time, hr*
Iron and steel	1100–1400	1–3
Stainless steel	1350–1600	1–2
Copper alloys	375– 575	1/2–1
Aluminum alloys	450– 500	1
Magnesium alloys	300– 600	1/4–1
Nickel alloys	1100–1200	1/2–1

* Manufacturers should be consulted for temperature and time for specific alloys and service conditions. The Codes for Unfired Pressure Vessels prescribe certain stress-relieving procedures for steels, and should also be consulted.

Sometimes stress relief annealing cannot be carried out because it may produce adverse effects on the properties and general corrosion resistance. This may be the case, for example, with some heat-treated aluminum alloys, and with stainless steels which are to be used in an environment where carbide precipitation results in intergranular corrosion. Stress-relief annealing may be impractical under some conditions as when the equipment is large. The procedure may be useless in composite structures where one metal is rigidly attached to other metals having different coefficients of expansion. The so-called low-temperature stress-relieving method[32] may have some merit in certain field-erected structures.

Usually complete elimination of internal stresses is not necessary. Changes in the method of manufacture may sufficiently lower the tensile stresses at the surface. Shot peening, tumbling, rolling, swaging, stretching, flexing, bending or straightening between rollers, depend on plastic deformation to decrease dangerous tensile stresses or to convert them into compressive stresses. Compressive stresses in a surface layer may not be a permanent remedy because the layer may be removed by corrosion. Changes in design may distribute the stresses more uniformly, as by increasing the number of supports in large vessels.

Removing or changing the corrosive agent is not as hopeless as it sounds. A reduction in temperature or dilution where possible may suffice.[29] A critical constituent may be removed if its presence is known. Inhibitors may sometimes be added as is done to combat caustic embrittlement. In the use of inhibitors care must be taken not to localize the attack and accelerate failure. Paints and protective coatings can be used to prevent the corrosive from contacting the metal. For example, painting magnesium alloys susceptible to stress corrosion cracking has increased their life four or five times. Anodic electrodeposits or thick pore-free cathodic electrodeposits have worked well. Cathodic protection or use of sacrificial anodes which stop the corrosion have stopped the cracking in many experiments. However, hydrogen embrittlement associated with the cathodic current might aggravate the cracking problem in some instances.

A sound method of avoiding cracking is to pick a resistant alloy. Occasionally comparatively small changes in composition may be helpful. Thus, lowering the zinc content of brass or the magnesium content of an aluminum magnesium alloy might be of benefit. Changes in deoxidation practice, heat treating and other procedures often have some effect on the cracking tendencies. On the other hand substituting one austenitic stainless steel for another has not prevented cracking in magnesium chloride, and alloying of steel has been of little help in resisting caustic embrittlement.

Theory of Stress Corrosion Cracking

No universally accepted theory of stress corrosion cracking has been developed, and it is not likely that the same mechanism applies in all cases. The principal theories have been reviewed by Harwood.[21]

The electrochemical theory developed by Dix[53] and his co-workers[54] postulates that intergranular cracking is tied in with the presence of anodic constituents at the grain boundaries. Tensile stresses are pictured as pulling the metal apart at any corrosion crevices and exposing fresh anodic material. Since potential relationships may change in different environments, it helps explain why cracking is observed only in specific corrosive media. It is pointed out that other continuous paths may exist besides at grain boundaries, for example, at slip planes and planes of precipitated constituents. Thus the theory may apply to transcrystalline stress-corrosion cracking. This theory seems well supported in the case of aluminum alloys and some other metal systems. Support for the theory is found in the fact that an applied potential making the system cathodic has prevented the stress-corrosion cracking of brass, aluminum, stainless steel, and magnesium.[23]

The film theory is rather similar but pictures the anodic areas as occurring at points of breakdown of a protective film. Once a notch is formed, tensile stress causes rupturing of protective films, and the exposed metal is anodic and corrodes. Modifications of this theory have been discussed by Evans[64] with emphasis on the film-forming tendencies at the tip of a crack.

The strain-accelerated decomposition theory postulates that the principal function or stress is to generate precipitation reactions or phase transformations which provide the anodic paths for corrosion.[65] Corrosion of the newly formed anodic material forms cracks, which concentrate the stress, which accelerates the decomposition and so on. In the case of steel, iron nitride is said to be the precipitated material. In the case of austenitic stainless steels, a martensitic decomposition product is suspected.

The mechanical theory as discussed by Keating[24] considers crack propagation as purely a function of stress systems tending to tear the metal apart. Electrochemical factors are considered important mainly in the initiation of the crack or crevice. It seems likely that the relative importance of the corrosive and the stress may change as cracking proceeds.

Hydrogen may play a role in some instances of cracking. Zapffe[27] insists that attack by hydrogen is responsible for the cracking of steel exposed to caustic with the mechanism being similar to attack by hydrogen at high temperatures.[9] Cathodic charging with hydrogen accelerated the stress cracking of chromium stainless steel in sodium chloride,[66] and hydrogen embrittlement may play a part in stress cracking in hydrogen sulfide.[39]

Other aspects of the problem have been discussed in the literature.[67, 68] Further development of the theory is to be expected as new work is carried out.

CORROSION FATIGUE

Fatigue failures of pressure vessels are an obvious hazard. The design engineer usually considers the fatigue characteristics of the materials, and this subject is thoroughly discussed in many places.[69] The difficulty is that fatigue tests are conducted in air where corrosion is presumably exerting little or no influence. If the metal is exposed to a corrosive environment, fatigue tests in air are almost meaningless.[70] Under such conditions the failures are a matter of corrosion fatigue which is much more drastic in its action.

It might be expected that exposure to a corrosive environment followed by subsequent fatigue testing would result in lower endurance limits. This has been shown to be the case.[71] The reason is the roughening of the surface by corrosion with resultant notch formation. This type of test, however, is not sufficient because the damage is much greater when corrosion goes on at the same time as the repeated stresses. The damage is greater than can be explained by the two factors acting additively.

For most corrosives, corrosion products and films tend to block or retard the attack or even to cause it to cease completely. Cyclic stresses tend to rupture or render more permeable these protective films. The result is that cyclic stresses accelerate corrosion. As already mentioned the roughening and pitting of the surface by corrosion forms notches which concentrate the stress, and thus accelerate the effect of applied cyclic stresses. These mutually accelerating processes continue until failure occurs by corrosion fatigue.[72]

In acid solutions where the possibilities of film formation are more remote, the mechanism may be somewhat different.[73] The cyclic stresses may produce distorted metal which is more susceptible to corrosion or it may change the area ratios and polarization characteristics of local anodes and cathodes. The formation of disarrayed metal may be important also during corrosion fatigue in neutral solutions.[74] The disarrayed metal seems more susceptible to corrosion only while it is in process of formation, and is no longer especially susceptible after it has had a chance to settle down. Additional aspects of the situation have been discussed by Evans and Simnad,[64, 75, 76] with particular emphasis on potentials and the behavior of local anodes and cathodes. In any case the effect of cyclic stresses is to in-

crease the corrosion and to cause the corrosion to form deep sharp pits and notches.[77]

Corrosion is the most important factor in corrosion fatigue. This means that tests should be run under the actual corrosive conditions to be encountered in service. This is not easy. Some of the problems connected with corrosion testing have been pointed out, and when cyclic fatigue stresses are added to the other test requirements, the problems multiply. All of the factors which influence normal corrosion would be expected to have some effect on corrosion fatigue.[78] Hence the composition of the corroding medium, the temperature, degree of aeration, and velocity must all be carefully controlled, and the possibilities of galvanic and other effects should be considered.

In addition, corrosion fatigue testing has some complications not present in fatigue testing in air. It is evident that, with sufficient time, corrosion alone will produce failure regardless of applied stress. It follows that in corrosion fatigue there can be no endurance limit. Furthermore since corrosion proceeds with time, the speed of testing has much greater influence than in fatigue. Sufficient time must be allowed for corrosion damage to occur. On the other hand the rate of stress application may control the damage to surface films, the chances of film repair and other factors controlling the acceleration of corrosion. Thus it is necessary to state the maximum repeated stress endured by a metal without failure in a stated number of stress applications under defined conditions of corrosion and stressing. Through common usage this is often called the corrosion fatigue limit.

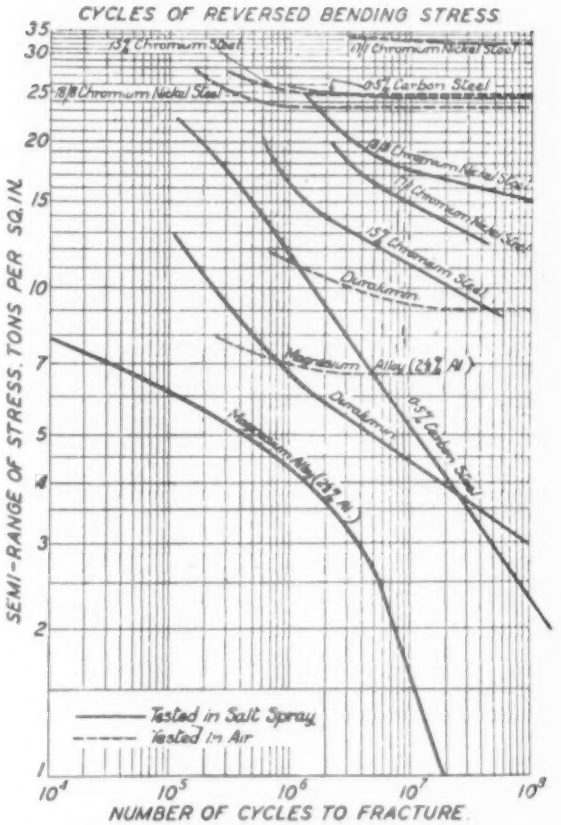

Fig. 12 Typical S–N curves in air fatigue and in corrosion fatigue in salt spray[81]

Table 2—Some Corrosion Fatigue Limits [82, 83]

(Stressed for at Least 10^7 Cycles at 1450 CPM)

Material	*Tensile strength, psi*	*Endurance limit in air, psi*	*—Corrosion fatigue limit, psi—* *Fresh water*	*Brackish water*
Carbon steels, annealed	46–103,000	25–42,000	16–23,000	5,000
Carbon steels, hardened	66–111,000	35–53,000	19–23,000	7,000
3.5 Ni steel, annealed	93,000	49,000	29,000	....
3.5 Ni steel, hardened	125,000	69,000	25,000	....
5.4 Ni steel, annealed	122,000	55,000	21,000	....
5.4 Ni steel, hardened	133,000	66,000	19,000	....
3.1 Ni, 1.6 Si steel, annealed	138,000	65,000	22,000	....
3.1 Ni, 1.6 Si steel, hardened	251,000	108,000	12,000	....
0.9 Cr, 0.14 V steel, annealed	59,000	42,000	22,000	....
0.9 Cr, 0.14 V steel, hardened	161,000	69,000	17,000	....
14.5 Cr stainless, annealed	94,000	52,000	36,000	36,000
14.5 Cr stainless, hardened	117,000	53,000	37,000	27,000
17.3 Cr, 8.2 Ni stainless	125,000	50,000	50,000	25,000
17.7 Cr, 25.3 Ni stainless	115,000	54,000	45,000	34,000
10.9 Cr, 34.7 Ni stainless	112,000	57,000	41,000	22,000
Nickel, annealed	78,000	33,000	24,000	22,000
Nickel, hardened	132,000	51,000	24,000	22,000
Monel, annealed	82,000	37,000	26,000	28,000
Monel, hardened	127,000	52,000	25,000	28,000
Nickel-copper, 21/78, annealed	47,000	19,000	18,000	18,000
Copper, annealed	31,000	10,000	10,000	10,000
Copper, hardened	47,000	17,000	18,000	18,000
Brass, 62/37 annealed	53,000	21,000	18,000	....
Brass, 62/37 hardened	84,000	24,000	18,000	....
Aluminum, annealed	13,000	6,000	....	2,000
Aluminum, hardened	21,000	8,000	5,000	3,000
Aluminum, 1.2 Mn, annealed	17,000	7,000	3,000	....
Aluminum, 1.2 Mn, hardened	30,000	11,000	6,000	4,000
Duralumin, annealed	33,000	14,000	8,000	7,000
Duralumin, hardened	69,000	17,000	8,000	7,000

As a consequence of the considerations, above, it is clear that corrosion fatigue limits in the literature can rarely be used directly for specific design purposes. Judgment and experience are essential in the application of corrosion fatigue data to operational problems. This can be illustrated by some work of Gould,[79] where he found that the endurance of steel to cyclic stresses in sea water as measured in a push-pull machine was five times that obtained in the usual rotating beam machine. In the push-pull machine all the anodic areas were exposed to yawning or stretching, whereas in the rotating beam machine only a fraction of the anodic areas were so exposed. This changed the anode to cathode area ratio and affected the development of sharp pits. This effect would vary greatly with service conditions.

Corrosion Fatigue Data

Some corrosion fatigue data are given in Fig. 12,[80, 81] Table 2[82, 83] and Table 3. Additional data in many other corrosives may be found in the literature.

Figure 12 shows some typical S–N curves for various materials as obtained in air and in salt spray. The ordinate logarithmically represents the semirange of stress, and the abscissa logarithmically represents the number of stress cycles to cause failures. Individual points are not shown but there usually is considerable scatter. The curves demonstrate that in air most metals have a very definite fatigue limit, that is a stress-range below which fracture is not expected to occur, however long the action lasts. Under corrosion fatigue conditions no such limit can be determined.

In Table 2 some corrosion fatigue limits are listed after at least 10^7 cycles at 1450 cpm for fresh water and brackish water exposures. This is a common method of expressing the results. The figures are of value in that they give a fair comparison of the corrosion fatigue behavior of metals. Table 3 illustrates another and perhaps better method of comparing data on the corrosion fatigue behavior of metals. It indicates the rapid damage at relatively high frequencies and relatively short periods of time. For example, in a little over one hour's exposure the strength of the high-strength nickel-silicon steel was reduced to 63% of its original value.

The important conclusion from the data is that corrosion fatigue properties depend primarily on the corrosion resistance under the test condition. The maximum resistance to corrosion fatigue is exhibited when the alloy is in the best condition to resist corrosion. Other forms of heat treatment and cold work, while affecting the tensile strength and the endurance limit in air, have little or no effect on corrosion fatigue. Thus in Table 2 the high-strength steels have a corrosion fatigue resistance close to that of plain mild steel. Alloying or changes in composition are beneficial only when they confer increased corrosion resistance.

In comparison with the low-alloy steels, the stainless steels showed greatly improved corrosion resistance and much greater corrosion fatigue resistance. The test conditions were favorable to the stainless steels in that the surfaces were polished and the solutions aerated. Under corrosive conditions tending to pit stainless steel the comparisons might be less favorable.

Nonferrous metals when resistant to the environment show favorable corrosion fatigue resistance. Thus Monel with half the endurance limit of steel was so much more resistant to the corrosives that under corrosion fatigue conditions it became a decidely stronger material in a relatively short time. Hardening treatments had little effect on the corrosion fatigue limits of the nonferrous metals, just as with the steels.

Copper was unique in that some of its corrosion fatigue limits were higher than its endurance limit. This has been attributed to the fact that some corrosion is occurring during fatigue tests in air due to the moisture and oxygen present.[70] With many metals the ratio of the fatigue limit in air to the fatigue limit in vacuum is close to unity. In the case of copper this ratio is 0.88, in the case of brass 0.79, and in the case of lead 0.45.[84]

It should be emphasized that the data in Table 2 pertain only to the corrosive conditions involved. Changing the environment is likely to change the picture. For example, in unaerated oil well brines containing hydrogen sulfide, low-alloy nickel steels have been markedly superior to unalloyed steels in resisting corrosion fatigue.[100, 101]

Identification of Corrosion Fatigue

A typical corrosion fatigue failure is shown in Fig. 13.[9] This is part of a propeller shaft which broke in service. General corrosion is slight but deep pits are present. Cracks are visible at many of the pits. The cracks are normal to the direction of the stresses. The presence of many cracks is a common characteristic of corrosion fatigue. These numerous cracks often result in the

Table 3—Corrosion Fatigue Data [82, 83]

	Tensile strength, psi	*Endurance limit, psi*	*Cycles →* / *Days →*	*Corrosion fatigue limits (fresh water), psi*			
				10^5 / *0.047+*	10^6 / *0.47+*	10^7 / *4.7+*	10^8 / *47+*
3.1 Ni, 1.6 Si steel	251,000	108,000		68,000	36,000	14,000	12,000
0.9 Cr, 0.14 V steel	161,000	69,000		83,000	48,000	20,000	17,000
Monel	129,000	52,000		86,000	61,000	34,000	21,000
Brass 62/37	84,000	24,000		....	....	20,000	18,000
Duralumin	69,000	17,000		30,000	17,000	11,000	8,000

Fig. 13 Corrosion fatigue failure of a propeller shaft.[9] Natural size

fracture having a serrated appearance. In fatigue in air there is rarely evidence of more than one crack. Other typical features are the smooth appearance of the fracture and ripple marks showing the point of origin.[70]

Under the microscope corrosion fatigue cracks generally appear similar to fatigue failures. Figure 14 shows a typical corrosion fatigue failure in a stainless steel tube. There is a pit at the surface, the crack is mainly transcrystalline and shows a marked tendency to follow slip planes. Under other conditions, as with steel in boilers,[85] corrosion products may fill the cracks and obscure fracture surfaces.

If fatigue failures are transcrystalline, as is the case in most metals, corrosion fatigue cracks are usually transcrystalline also. If fatigue failures are intergranular as in lead, corrosion fatigue cracks are intergranular. However, where the corrosion under stressless conditions or under static stress is intergranular, the corrosion fatigue cracks may be intergranular. Figure 15 shows a corrosion fatigue crack in an Inconel airplane boiler, where the cracks are partly intergranular and partly transcrystalline.[86] Here precipitation of intergranular carbides at the temperature of service facilitated the intergranular attack. Instances are known where the cracks started out in intergranular fashion and wound up completely transcrystalline. This is interpreted as indicating the predominance of corrosive influences at the start of the attack, and the predominance of fatigue after the attack was well started.

Protection Against Corrosion Fatigue

Noncorrosive and sacrificial metallic coatings suggest themselves, but it is necessary to make tests to be sure what the results will be.[87] Some coatings may decrease the fatigue strength in air, and still improve the corrosion fatigue limit in some environments. Of course, the benefit of any coating is gone as soon as the coating breaks down.

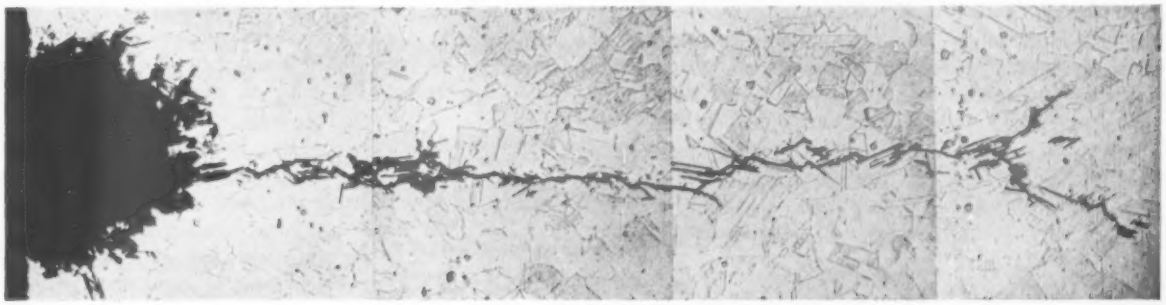

Fig. 14 Corrosion fatigue crack in a stainless steel tube. 250 ×

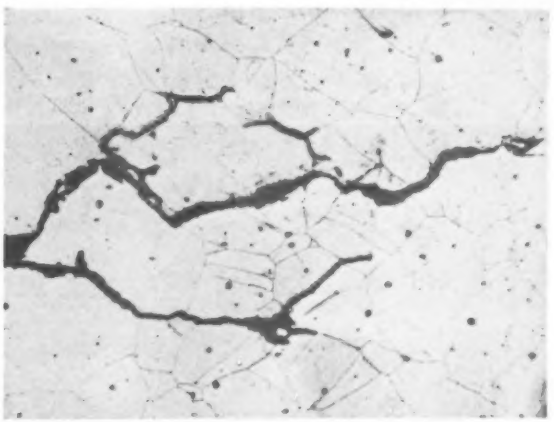

Fig. 15 Corrosion fatigue crack in an Inconel airplane boiler, partly intergranular and partly transcrystalline.[86] 100 ×

Cathodic coatings, such as nickel and copper on steel, should be thick enough to remain pore-free. Data have been reported showing that nickel electrodeposits on steel were beneficial under corrosion fatigue conditions in sodium chloride spray.[88] Chromium plating provided considerable protection to steel in steam.[89] In the case of composite coatings the behavior is difficult to predict.[90]

Anodic coatings need not be pore-free because they provide sacrificial protection by preventing corrosion. Zinc coatings were discussed by Harvey.[91] In galvanizing, the brittle zinc-iron alloy might favor the inception of cracks, and in electroplating fear has been expressed that there might be hydrogen embrittlement of the steel base. However, hydrogen embrittlement has been found to have no effect on corrosion fatigue where the stressing was within the elastic range.[92] Metal sprayed coatings of zinc, cadmium and alumi-

Fig. 16 Fatigue crack around a fitting which started at a deep groove formed by corrosion in the crevice on the inside where the fitting joined the tank

num on steel have been used[93] and also paints highly pigmented with zinc.[78]

The corrosion fatigue behavior of coatings is influenced by internal stresses. Tensile stresses in plated coatings seem harmful and compressive stresses beneficial. Nitrided steels exhibit exceptional resistance to fatigue owing to the compressive stresses present. These compressive stresses in nitrided steels have been shown to be beneficial as well under some corrosion fatigue condition.[59] Shot peening to produce surface compressive stresses likewise has been shown beneficial in corrosion fatigue tests in sea water and sulfuric acid.[94] The effects of shot peening, however, are complicated, and in solutions with high alkali content shot peening was harmful under corrosion fatigue conditions apparently because it localized the attack.

Corrosion inhibitors can be helpful in corrosion fatigue, and their effect parallels their influence on normal corrosion. The danger with inhibitors is that they may fail locally, either due to insufficient quantity of inhibitor or to local conditions such as the presence of crevices.[95] A similar danger exists with the use of an applied cathodic current in that an interruption in the protection might allow a few sharp pits to develop, which would be more harmful than the more general attack in the absence of protection. In hydrochloric acid a cathodic current failed to have much effect on the corrosion fatigue life, probably because the current could not reach the tips of the developing cracks.[73]

Fig. 17 Cracking on outside of a stainless steel tube. Natural size

LOCAL ATTACK

At the start it was pointed out that local attack by corrosion could form dangerous notches and grooves in pressure vessels. A number of causes for such local attack were listed. Under suitable circumstances such attack might be caused by galvanic corrosion. Such local attack might occur in the crevices formed by reinforcing rings or at crevices around fittings. Such corrosion does not cause cracking itself, but it may lead directly to cracking through its weakening effects. Figure 16 shows a fatigue crack around a fitting in a tank. The crack started in a groove formed by crevice corrosion on the inside. The crevice occurred where the fitting joined the tank. Without this crevice the corrosion behavior would have been satisfactory, and without the notch formed by corrosion the fatigue behavior would have been satisfactory.

INTERGRANULAR ATTACK

Some metals under proper conditions of heat treatment and in suitable environments are susceptible to intergranular corrosion. A number of examples were listed by Rawdon.[58] This is distinct from stress-corrosion cracking. It depends on the metallurgical conditions of the alloy.[96] A classic example is the intergranular corrosion of stainless steels which may occur when the temperature or heat treatment is such as to precipitate carbides at the grain boundaries and cause chromium depletion. Such intergranular attack when it occurs is accelerated and localized by tensile stresses. It would be particularly dangerous

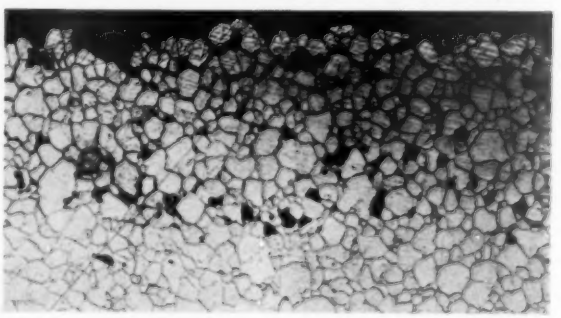

Fig. 18 General intergranular attack on inside of the tube in Fig. 17, which was accelerated locally to produce the cracking

in pressure vessels and could lead to rapid cracking. The remedy, of course, is to avoid alloys and conditions which produce this kind of attack.

Figure 17 shows a crack on the outside of a stainless steel tube. The crack tends to wander around but it would be difficult to classify it from its superficial appearance. Microexamination showed that the entire inside surface of this tube had suffered severe intergranular attack as illustrated in Fig. 18. This general intergranular attack was accelerated locally and led to the cracking. In this case the corrosion and cracking could have been prevented by proper heat treatment of the stainless steel.

EFFECT OF STRESS ON GENERAL CORROSION

There is a widespread belief that static stresses invariably increase the rate of general corrosion. There is little to substantiate so broad a belief. In most instances it appears that the effect of normal amounts of static stress on uniform corrosion are comparatively small. It can be said that no recognized problems exist in this connection. If the metal is of normal quality and the customary factors of safety are employed, the design engineer scarcely needs to concern himself with acceleration of weight loss by corrosion due to static stress.

The expectation of increased corrosion is usually based on the fact that energy may be stored locally in distorted metal, and this should make it less noble. Potential measurements given in the literature are conflicting, but this point has been clarified.[76] The potential of the freely corroding metal may not change greatly even though the potential of the local anodes on open circuit has shifted in the less noble direction. Furthermore it is well known that relative potential by itself gives no certain indication of corrosion behavior. The electrochemistry of stressed metals has recently been reviewed by Simnad.[75]

The literature contains an extensive but conflicting array of data, opinion and comment on the effect of static stress on uniform corrosion. Some data by the author appear in the *Corrosion Handbook*.[9] Evans[24] has attempted to rationalize the situation, and feels that any effect of cold work on corrosion would be evident only below pH 4. In neutral solutions the rate of corrosion is often controlled by the rate of supply of oxygen, and hence cannot be increased by stress. In accord with this, most examples of stress increasing corrosion are in acid solutions, but even in acids there appears to be no general rule.

EFFECTS OF HYDROGEN GENERATED BY CORROSION

Many instances of hydrogen attack of steel pressure vessels are recorded in the literature. At high temperatures and pressures the attack is fairly well understood.[5] It is a matter of hydrogen diffusing into the steel and reacting with carbides and other constituents to form methane and other products. High gas pressure at localized sites within the steel results in fissuring. Severe attack can usually be prevented by alloying with suitable elements to form stable carbides.[97]

At lower temperatures the hydrogen generated by corrosion in aqueous solutions can also cause damage to steel although the nature of the attack is different. Atomic hydrogen formed by the corrosion reaction diffuses through steel quite readily. Dissociated hydrogen can also leave the steel. However, if the rate at which hydrogen enters steel is greater than that at which it leaves, internal pressures build up owing to the accumulation of molecular hydrogen in rifts or pockets, and cause embrittlement, blistering and fissuring.[98, 99] These effects obviously weaken the steel. An instance has been recorded where they were responsible for the head blowing off a pressure vessel.[89]

The factors which control the rate at which hydrogen enters steel are not well understood. Many corrosion reactions are harmless even though plenty of hydrogen is generated. It seems certain that the surface of the steel must actively promote the acceptance of atomic hydrogen rather than catalyze the association of atoms to molecules of hydrogen gas. The presence of sulfur, arsenic, selenium, tellurium, antimony and phosphorus promote hydrogen absorption. Once hydrogen accumulates in steel it is bound to produce embrittlement and loss of ductility, which shows up as cracking on bending. Blistering and fissuring may depend in part at least on the quality of the steel.[99]

Hydrogen sulfide is the bad actor in promoting hydrogen damage in many instances. However, iron sulfide corrosion products seem to be protective and slow down the corrosion and entrance of hydrogen. The co-presence of acidic material such as acetic or formic acid increases the hydrogen penetration probably by removing the protective iron sulfide. In alkaline solution cyanide may react with and remove the iron sulfide and lead to continued activity.[99] This tie-in of hydrogen sulfide and cyanide is reminiscent of some so-called stress corrosion cracking failures,[26, 27] and raises the question of how far hydrogen embrittlement may be involved.

It has definitely been shown that charging with hydrogen accelerated the stress corrosion cracking of 13% chromium steel in sodium chloride.[66] It also seems likely that hydrogen played a part in the cracking of steel in a high pressure gas condensate well containing hydrogen sulfide and carbon dioxide.[39] The whole subject of the damage which can be caused to pressure vessels by hydrogen generated by aqueous corrosion needs further study. This is particularly true where the effects of hydrogen may be in combination with other phenomena such as stress-corrosion cracking.

FIELDS FOR FUTURE RESEARCH

Economics make it no longer acceptable to hide ig-

norance by ample overdesign to take care of the unknown in corrosion. Therefore it becomes important to learn more about corrosion theory and corrosion mitigation.

In neutral solutions the corrosion of iron is controlled largely by the amount of oxygen available. Small changes in composition, type of heat treatment, surface preparation and internal stresses have little or no effect on over-all weight loss. However, such factors can localize the attack and promote pitting or cracking. This aspect needs further study. Perhaps one way of doing this is to study the electrochemistry involved, to determine the potentials of local anodes and cathodes, the area ratios and the polarization curves. Similar remarks apply to other alloy systems as well as iron and steel.

In acid solutions hydrogen evolution is the major cathode reaction and probably controls the corrosion. Here the behavior of the minute cathodes on the metal surface becomes dominant. More needs to be known about hydrogen overvoltage, and the effects of surface finish, inclusions, alloying elements, surface films and corrosion products. What determines whether the hydrogen will enter the metal or be evolved as a gas?

At present corrosion is prevented by cathodic protection, by metal coatings, by organic coatings, by inhibitors, by treatment of the environment and by the use of alloys. But, as indicated in the text, the application of these methods to the prevention of cracking needs further study.

Cathodic protection applied too late, for example, may not stop the growth of cracks already existing. Underprotection may actually localize the attack and hasten a failure due to cracking. Overprotection with too much current may cause hydrogen embrittlement and resultant complications. Some easy and satisfactory means of establishing when complete cathodic protection is attained is urgently needed. Also needed are quantitative data relating the corrosion factors of the environment (temperature, aeration, velocity, pH, dissolved salts, galvanic couples, time, etc.) to the minimum current for total protection. Substantially similar remarks could be made for the use of inhibitors. A better understanding of the mechanism of their action and of their proper application is needed.

Returning specifically to stress-corrosion cracking, there is no way of knowing whether an alloy will resist cracking in a given environment except by trial and error. It is not known why some environments produce cracking and others do not. The theory and mechanism of stress corrosion cracking needs further development with detailed knowledge of the influence of internal structure, the magnitude and distribution of stresses, and the influence of the environment. How do minor constituents in the environment act as accelerators or as inhibitors of cracking? What determines whether the path of the crack will be intergranular or transcrystalline? Also the roles, if any, of hydrogen in stress corrosion cracking should be tied down. More needs to be known about the effect of changes in composition, heat treatment and structure of metals and alloys. It is not yet certain whether a susceptible alloy can be improved, purified or modified to make it acceptable under some conditions.

With reference to corrosion fatigue much more data are needed under actual service conditions. Corrosion fatigue limits vary with the corrosive environment, but with a sufficient background of information it should be possible to make intelligent appraisals concerning behavior in new environments. Quantitative data are needed relating corrosion fatigue limits to the corrosive factors of the environment, such as temperature, aeration, velocity, pH, etc. More information is needed also on the various protective measures which have been suggested. The theory needs further development particularly as to mechanism by which stress accelerates corrosion. Measurements of the potentials of local anodes and cathodes, area ratios and polarization curves would be elucidating.

The factors which control the entrance of hydrogen into a metal are not well understood. Just how the hydrogen behaves after it gets in the metal is also not clear, although it is certain that its effects can be damaging and can promote cracking. This whole subject of hydrogen damage in aqueous solutions needs further study, particularly where it ties in with cracking of pressure vessels.

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Ductile Welding of Zirconium

by F. G. Cox, B.Sc. Ph.D., A.R.C.S., D.I.C.

ZIRCONIUM is one of the group of metals always regarded as brittle but which, in the last few decades, has been produced in ductile form. Being more plentiful than such metals as nickel and copper it is by no means rare, but large-scale production has been retarded until recently because of the difficulties created by its great affinity for all the common gases. Zirconium is, in fact, stable at elevated temperatures only in the presence of the truly inert gases—the elements of Group O of the periodic classification—and complications arising from its affinity for the common gases have been the main difficulty encountered in the processing and fabrication of the metal. Hot forging and hot rolling must be done in a mild steel sheath, annealing has to be carried out *in vacuo* or in an atmosphere of pure inert gas, and welding by the oxy-acetylene or the normal metallic arc process is impossible. It is true that zirconium can be heated to temperatures of the order of 800° C in air for a matter of minutes without deleterious effect on its ductility, but the tough film of oxide formed on the surface of the metal is extremely difficult to remove.

As the most promising commercial property of zirconium is its high resistance to corrosion, in particular to hydrochloric and nitric acids in all concentrations, to dilute sulphuric acid, most organic acids and the alkalis, it must be capable of being welded without the loss of any of its corrosion resistance properties and in welds for applications involving pressures over that of the atmosphere, ductility is essential. Satisfactory welds can be made by spot welding and seams can be made by a succession of spot welds; but this does not cover all welding requirements, and a means of fusion welding without loss of ductility had to be determined.

The conditions under which a metal is melted during manufacture usually bear some relation to the conditions under which it can be welded. In the production of zirconium in the form of cast ingot the metal is melted under a vacuum of the order of 1 μ, and while this can be maintained in a suitable furnace it would be impracticable, if at all possible, to maintain such a vacuum under fusion welding conditions. It has been found that ductile zirconium can be produced by melting in an arc furnace in an atmosphere of pure argon, and it should therefore be possible to weld zirconium in an atmosphere of argon provided precautions are taken to ensure the necessary purity of the gas throughout the welding operation.

A process has been developed since 1930 for arc welding, in an atmosphere of inert gas, the reactive metals and alloys such as aluminium, stainless steels, magnesium alloys, etc. In America helium occurs in some natural gases in concentrations which permit economic extraction, and it is customary in that country to use it in the "Heliarc" welding process. In this country argon is generally used as the shield in welding metals of the type mentioned because it is the most abundant inert gas in the atmosphere. The argon-arc welding process consists essentially of striking an arc between a nonconsumable tungsten electrode and the metal to be welded, both the electrode and metal being protected by an atmosphere of argon. Equipment for argon-arc welding, being readily available and widely used, became, with modifications, the obvious choice for welding zirconium.

The production of ductile welds in zirconium, titanium and tantalum has been mentioned in the literature,[1,2] but no details are given beybnd the statement that when heated to a temperature of or above 1200° F all metals must be completely shielded. In the case of zirconium, however, it has been reported[2] that welds made using direct current are significantly more ductile than those made under similar conditions but with alternating current.

The scarcity of published information increases interest in the subject, and in the following pages the experiments made to determine the conditions necessary for the production of ductile welds in zirconium are described, the chemical and physical properties of the welds are discussed, and an account is given of the developments needed to adapt the process to production practice.

EXPERIMENTAL

A standard Mk. III "Argonarc" welding torch designed to carry up to 300 amp was used throughout the experiments. This comprises a tungsten electrode mounted in a brass collet, adjustable to accommodate various gauges of tungsten rod. The electrode is enclosed by a ceramic hood (suitably tapered at the open end to ensure a streamline flow of argon on to the weld), which is interchangable with a range available to suit the size of electrode in use. The welding current is supplied through a water-cooled copper cable and the whole of the electrode is water cooled. Current supply for a-c welds was taken from a standard welding transformer; for d-c welds it was taken from a welding generator of normal type.

Argon of standard welding quality was used for all the welds; it was described as not less than 99.80% pure, but purity was not checked. The advisability of purifying the gas was considered at the outset because absolutely pure argon was thought to be essential to ensure ductile welds; but it was decided not to treat or purify the gas in any way, and subsequent results indicate that, up to a certain thickness of zirconium, ductile welds can be made with the use of standard welding quality argon as a shield. Argon from several cylinders was used to eliminate the possibility of the gas from any one being of exceptional purity.

Apart from one or two special cases in which thicker material was used, the welds were made on 0.030- and 0.060-in. zirconium sheet. Both sizes were welded with simple butt joints, the former without filler rod and without edge preparation apart from ensuring straight edges. In the case of the thicker sheet the edges to be welded were chamfered to 45 deg and zirconium wire 0.050 in. diam was used as a filler rod. Before use the filler rod was carefully cleaned by rubbing with emery cloth to remove all traces of oxide film and drawing lubricant.

In the welds made with direct current the electrode was coupled to the negative pole of the current supply so that the hot, positive crater of the arc was on the sheet and not on the electrode. Welding with the reverse polarity was impracticable, as the tungsten electrode tended to melt,

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with consequent contamination of the weld. Alternating-current welds were made using a current of 55 amp for the 0.030-in. sheet and 65 amp for the 0.060-in. sheet with, in both cases, an open-circuit voltage of 100. For the d-c welds the currents used were 45 and 55 amp, respectively, at an open-circuit voltage of 60, falling to 25 v when the arc was struck.

A special jig was used to hold the sheets in position during welding. Each was clamped to a piece of $^1/_4$-in. thick steel plate, with the edges to be welded slightly overlapping the plates. The plates were then clamped to a larger plate in a manner which allowed the edges of the zirconium sheets to touch accurately, and every precaution was taken to avoid contamination of the weld by iron. In this way a narrow gap was formed under the joint; the width of the gap controlled the extent of the heat affected zone but allowed penetration right through the weld without danger of contamination. A stream of argon was directed through the gap to protect the back of the weld. In open welding the argon steam at the back of the weld is essential; it is dispensed with when welds are made in the totally enclosed shield described later. The most satisfactory gap width for the 0.030-in material was found to be $^1/_4$ in.; for the 0.060-in. section and thicker a gap width of $^3/_4$ in. gave best results.

To avoid contamination of the weld with tungsten from the electrode, the arc would normally have been struck with the aid of a high-frequency current of the order of 1500 v and a few milliamperes imposed on the welding circuit. The high-frequency current tends to stabilize the arc, which can be established without the electrode touching the work, but as this refinement was not available the arc was struck on the extreme edge of the sheet to be welded and this portion was trimmed off after welding. No difficulty was experienced in maintaining a steady arc, and experimental welds were made to ascertain the embrittlement in welds made with the torch as described, and to examine the reported difference in welds made with direct and alternating current. Tests using alternating current showed that variations in the flow or argon up to 50 cfh had no effect on the brittleness of the weld, but at higher flow rates the arc was unstable and welding became impossible. The use of direct current for welding thin sheets showed marked improvement on the results obtained with alternating current; ductile welds were obtained with an argon flow through the torch of 14 cfh or more, but slower flow rates led to some embrittlement. The pool of molten metal is much smaller when direct current is used, and it is considered that welds made with the smaller pool, arising from the use of direct current, show increased ductility because the argon stream affords adequate protection for the smaller heat-affected zone. This theory was confirmed by the embrittlement apparent in welds made with direct current on heavier-section material. A piece of 0.110-in. sheet (annealed hardness 160 VPN) welded with a zirconium filler rod of similar hardness gave a hardness in the weld of 230 VPN, and a fillet weld made between two pieces of 0.030-in. sheet at right angles, the backs of the sheets being protected with a stream of argon, was found to be so brittle that it withstood no distortion without fracture. The extent of the molten zone in both these welds was comparable to that arising from the use of alternating current.

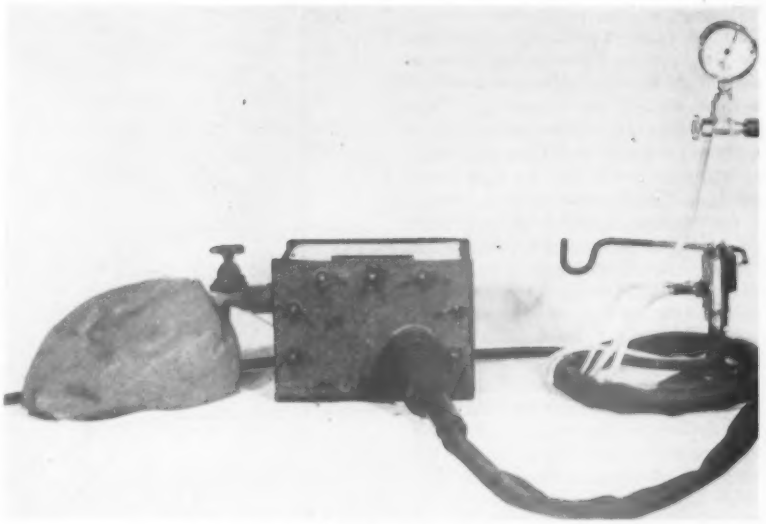

Fig. 1 Welding box with torch in position

It was decided at this stage that commerical quality argon is sufficiently pure for the production of ductile welds in thin sections of zirconium providing there is no contamination from outside the gas shield. To prove this, and to determine the conditions necessary to ensure ductile welds in heavier sections, it was decided to eliminate all possibility of contamination by welding in a totally enclosed box.

The box (Fig. 1) measured 9 x 7 x 7 in. It was constructed of mild steel with a perspex cover, the torch being fitted at the front through a gas-tight, convoluted rubber seal. Provision was made through one side for the manipulation of a filler rod, which passed through a small hole covered with sheet rubber held in position by a flange. Welds up to 4 in. long were made in this equipment, and to ensure that it was completely flushed with argon the box was twice exhausted to a pressure of 1 mm of mercury by means of a rotary oil pump, argon being admitted between the two exhaustions.

Even though the torch was water cooled it was found necessary to maintain a flow of argon through it to keep the electrode and shield cool. The flow of argon also maintained a positive pressure inside the box to prevent any possible infiltration of air, and for convenience the expelled argon was collected in a rubber meteorological balloon; it could have been equally well exhausted through a bubbler containing sulfuric acid or dibutyl phthalate.

The use of the box resulted in the production of ductile welds, using either alternating or direct current with or without a filler rod, and the welds were capable of immediate reduction by cold rolling. The molten zone appeared silvery white immediately after welding but tarnished slightly on exposure to the atmosphere. The normal coloured bands were present on the heat-affected zone of the sheet but this was to be expected after heating in an atmosphere containing traces of oxygen and nitrogen, and it is rather surprising that ductile welds can be made at all in argon of the purity used. The probable explanation is that the time the zirconium remains molten is so short that extensive pick-up of impurities is avoided. This was confirmed in a weld made on two pieces of 0.320-in. thick material. The edges were chamfered to 45 deg and the weld was made in three runs, using a $^3/_{16}$-in. filler rod. Although it proved to be mechanically sound the hardness had increased somewhat—from 181 VPN on the original slab and 190 VPN on the filler rod to 264 VPN on the weld. The work had remained hot very much longer than would have been the case with sheet, and any film formed on the first or second run was dissolved by succeeding runs. For sections such as this, purified argon would be necessary to obtain welds as soft and ductile as the parent metal.

PHYSICAL PROPERTIES

Variations of hardness across the welds

were measured on a Vickers hardness testing machine. The testing load of 20kg was the maximum possible on 0.030-in sheet for the hardness anticipated without interference with the supporting table. It has been ascertained that the apparent hardness is a function of the applied load, the variations being less the higher the load applied, and for the sake of uniformity all the hardness figures mentioned were measured with an applied load of 20 kg.

Hardness scans were made across eight welds in 0.030-in. sheet. Four were made with direct current and four with alternating current. Each series of four included an annealed and an unannealed weld made with the unmodified torch, and an annealed and unannealed weld made in the box. Annealing was effected by heating to 800° C in air for 15 sec; the very fine film which formed during this procedure had no noticeable effect on the measured hardness value. The results of these tests are plotted in Figs. 2 and 3. It is significant that in both the annealed and unannealed welds made in the box the weld metal is at least as soft as the adjacent metal, and indication that if any embrittlement does occur in the weld it is no more pronounced in the molten zone than in the immediately adjacent unmelted metal. Although the welds made with the unmodified torch, using direct current, were ductile there are indications that those made in the box are slightly softer, the actual difference being approximately 20 VPN.

Sheets welded in the box, with or without filler rod, can be reduced by as much as 75% by cold rolling before annealing becomes necessary. The weld is in fact, often softer than the parent sheet, and after rolling it is sometimes found that a welded sheet with a general thickness of say, 0.013 in. measures only 0.012 in. along the line of the original weld. It is not usually necessary to remove high spots from the welds before rolling, as they are rolled down on the first pass through the mill, and unless importance is attached to the appearance of the finished sheet no treatment is necessary prior to rolling. When appearance is important, the oxide film is removed by sandblasting and a bright surface obtained by pickling in a 35% nitric acid solution containing approximately 1% of hydrofluoric acid.

For general interest and for comparison with the hardness scans an attempt was made to measure the temperature gradient across the weld during welding. This was done by painting two strips of zirconium with "Thermindex" paints and welding them together in the usual manner the change in color of the paints indicating the temperature attained at given points. The weld was made in 0.030-in sheet held in the jig previously described, the gap under the joint being 1/4 in. wide. The method was only approximate, as the time of heating was less than that recommended in the use of the paints, but it was possible to obtain a check point. On heating zirconium above 862° C a transformation occurs from the hexagonal or α modification stable at room temperature to the high-temperature cubic β modification[4] which is unstable at room temperature; so far it has not been found possible to retain this structure by quenching. The microstructure of zirconium which has been heated above the transformation temperature without melting is unmistakable, and the junction of this zone with that of the untransformed structure can be clearly seen. By measuring the distance of this boundary from the edge of the molten zone one point in the temperature gradient can be determined. The distance between the points mentioned measured 4-mm and was the same for welds made by either type of current. This was to be expected, because the temperature gradient between the edge of the molten zone and the un-

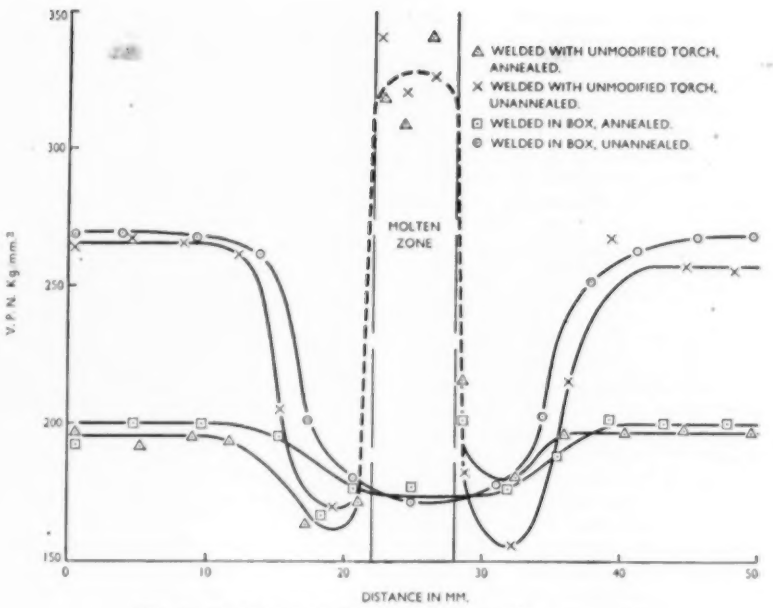

Fig. 2 Variations in hardness (alternating current)

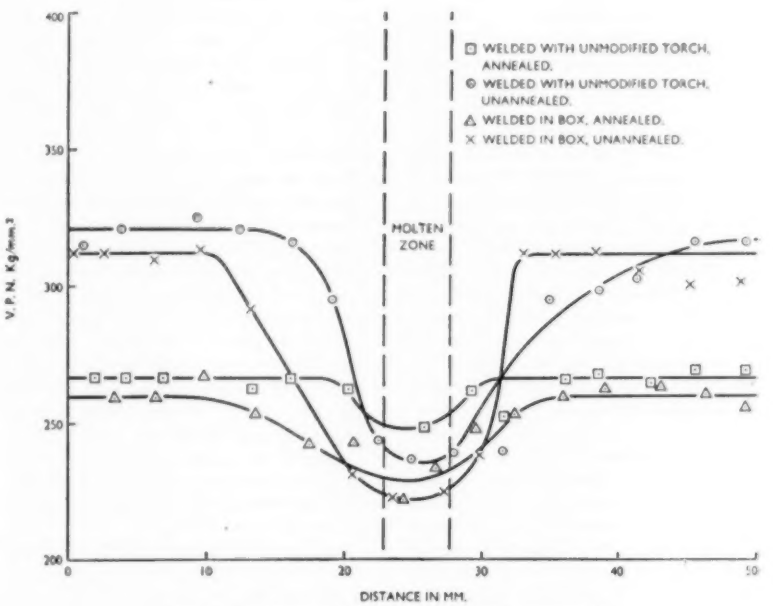

Fig. 3 Variations in hardness (direct current)

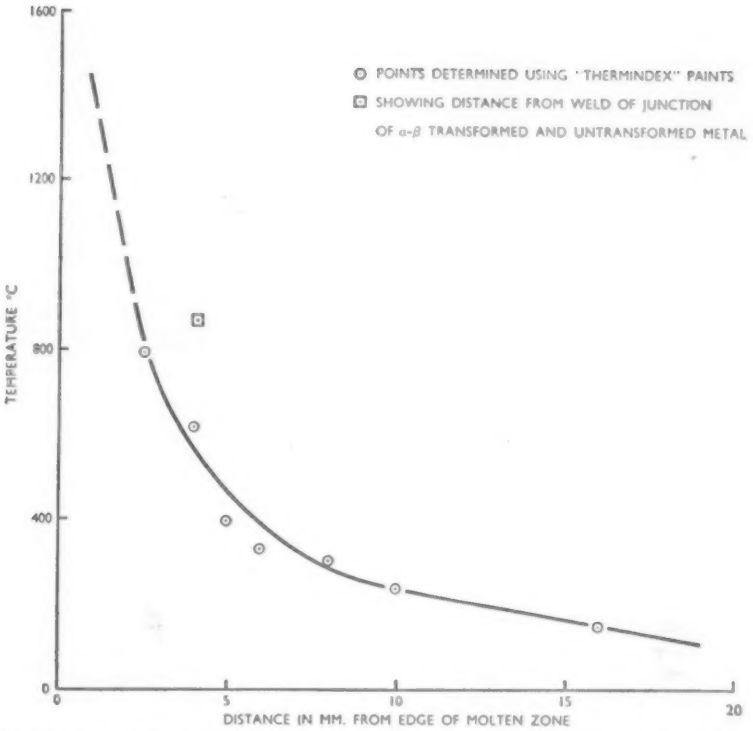

Fig. 4 Temperature gradient across a weld made in 0.030-in. zirconium sheet

heated portion of the sheet is unlikely to be affected by the width of the molten zone. The position of the point shows that, in this particular instance, the temperatures indicated by the paint are somewhat low. The temperature gradient is represented graphically in Fig. 4. Comparing the temperature gradient with the hardness scans and bearing in mind that the recorded temperatures are rather low, it would appear that some annealing or, to be more precise, some stress relieving has occurred in the areas heated to the region of 400° C.

Other physical properties of the welds are given in Tables 1 and 2. All the tests were made on 0.030-in. sheets reduced to 0.015 in. either by grinding, to remove inequalities in the thickness of the weld, or in the case of specimens BP42 and BP84–87, by rolling. The results for a-c and d-c welds are shown separately, as different sheets were used for the two series of tests—a point to be borne in mind when the results are considered—and it should be noted that the results obtained from similar tests on the unwelded parent metal have been included. All a-c welds were made in the box.

The tensile strengths of BP40 and BP41 are similar because of the occurrence of some annealing during welding. Figures for elongation and reduction of area of BP41 are not available, as some elongation occurred outside the gauge length. The figures for BP42 of welded material in the hard-worked condition compare favourably with those of BP43 in a similar state of work.

Bearing in mind the difference in the mechanical properties of the original sheet, these figures indicate that the type of current used (a-c or d-c) has no significant effect on the mechanical properties of welds made on zirconium sheet, whether the welds are made in the box or, in the case of d-c, with the unmodified torch. This is to be expected and applies only to thin sheet, as it has already been established that thicker sections are embrittled when welded with the unmodified torch. As in the case of a-c welds, the figures for the annealed and unannealed welds are similar because of the annealing which occurs during welding. Again the figures for welds in the hard-worked condition (BP84 and BP86) compare favourably with those for the parent sheet (BP88) in similar conditions.

CHEMICAL PROPERTIES OF WELDS

The main interest in the chemical properties of welded zirconium naturally bears on its resistance to corrosion. Because the mechanism of the corrosion of zirconium is not yet fully understood the opinions expressed must be empirical,

Table 1

**Tensile Tests on Zirconium Sheet welded by Alternating Current*

Sample No.	Description	U.T.S. (tons/in.²)	Elongation (%)	R.A. (%)
BP40	Welded, unannealed	32·3	14	25
BP41	Welded, annealed	33·3	Not measured	
BP42	Welded, annealed and rolled to 0·015 in., unannealed	44·7	3·5	5·5
BP43	Unwelded, unannealed	41·5	7	19
BP44	Unwelded, annealed	25·3	10	34

* The tensile tests were made by Dr. Eborall of the British Non-Ferrous Metals Research Association.

Table 2

**Tensile Tests on Zirconium Sheet welded by Direct Current*

Sample No.	Description	U.T.S. (tons/in.²)	Elongation (%)	R.A. (%)
BP80	Welded in air, unannealed	45·6	4	8
BP81	Welded in air, annealed	43·1	10	21
BP82	Welded in box, unannealed	42·6	4	19
BP83	Welded in box, annealed	43·6	8	18
BP84	Welded in air, annealed, rolled to 0·015 in., unannealed	60·7	4	6
BP85	Welded in air, annealed, rolled to 0·015 in., annealed	45·7	15	26
BP86	Welded in box, annealed, rolled to 0·015 in., unannealed	60·2	3	11
BP87	Welded in box, annealed, rolled to 0·015 in., annealed	43·3	12	14
BP88	Unwelded, unannealed	52·5	4	12
BP89	Unwelded, annealed	38·0	4	18

* The tensile tests were made by Dr. Eborall of the British Non-Ferrous Metals Research Association.

but the observations made and the results obtained in investigating the chemical properties of the welds can only increase the considerable interest already shown in the subject.

Corrosion resistance tests were made by immersing the specimens for 24 hr, at room temperature, in a bath of concentrated hydrochloric acid containing 1 g/l of iron. The iron addition was made because corrosion in the resulting solution is much more drastic than in the acid alone. To increase the corrosion conditions still further, the specimens were rotated in the bath at 300 rpm. All trace of oxide film was removed from the specimens with emery paper before immersion. The photograph (Fig. 5) shows the condition of the specimens after treatment in the corcorrosive bath and Table 3 gives particulars of welding, together with the iron and carbon content of the welds.

It will be clearly seen in the photograph that the actual welds and the adjacent heat-affected metal are more highly resistant to corrosion than the parent sheet, and this improvement in the corrosion resistance of the welds has been displayed by all specimens tested to date. Examination of the corroded areas under the microscope at low magnification shows the type of corrosion to be the same on both the weld and the original sheet, the surface of the metal being deeply pitted in both cases, but corrosion is not even over the whole sheet. The pits are larger and deeper on the non-heat-affected metal than on the welds and there is a sharp division, shown up by the corrosive attack, between the heat-affected zone and the original sheet. Resistance to corrosion appears to be the same, irrespective of the method of welding or the type of current used. The relative corrosion resistance of the weld metal and the original sheet is unaltered after 50% cold reduction, the weld remaining far superior to the sheet. The reason for the superior corrosion resistant properties of the weld and of the heat-affected area is not easy to find, but it could possibly be due to the burning out of carbon during welding. Chemical assay for carbon on the weld metal and on the original sheet containing 0.07% C has shown a reduction to 0.04% and there are indications in the microstructure that the carbon may be somewhat lower in the weld than in the original sheet, but this would hardly account for the high corrosion resistance of that portion of the welded sheet which has been heat-affected but not melted. Assay showed no appreciable change in the amount of nitrogen present in either case. It is possible that the cast surface is more resistant to corrosion because of the size of the carbide particles, or it may be due to the fact that this surface is strain-free In this connection it is interesting to note that the difference in corrosion resistance is maintained on working. When the mechanism of the corrosion of zirconium is understood more clearly a fuller explanation will be forthcoming.

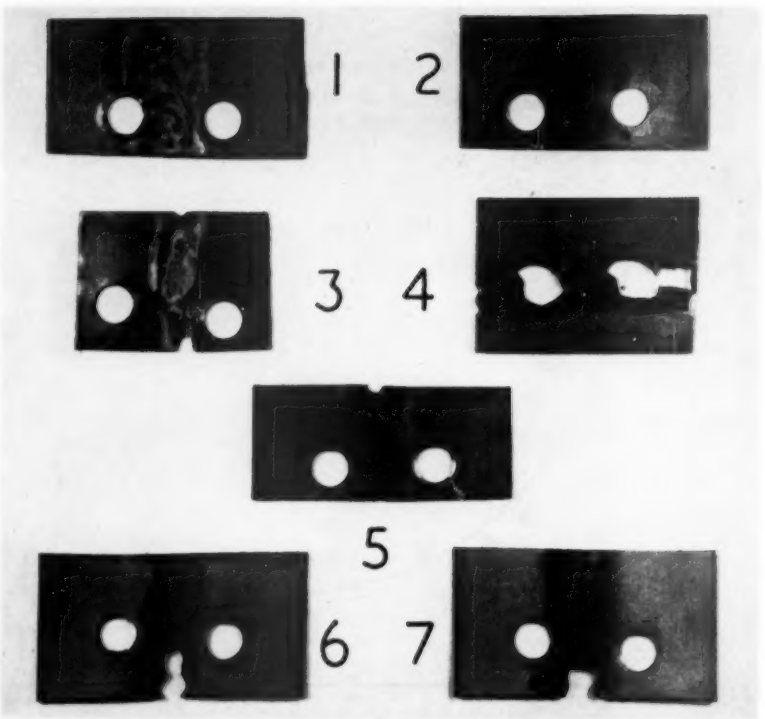

Fig. 5 Welded zirconium sheet. Test pieces after immersion in corrosive bath

Table 3
Description of Corrosion Test Pieces

No.	Fe (%)	C (%)	Method of Welding
1	0·08	0·11	A.C. with unmodified torch
2	0·08	0·11	A.C. welded in box
3	0·03	0·05	A.C. with unmodified torch
4	0·03	0·05	A.C. welded in box
5	0·02	0·03	A.C. welded in box
6	0·08	0·20	D.C. with unmodified torch
7	0·08	0·20	D.C. welded in box

MICROSTRUCTURE

The photomicrographs (Figs. 6 and 7) illustrate the variation in structure at different distances from the molten zone of the welds in both the annealed and unannealed states. Annealing comprised heating to 750° C for 3 hr in a static atmosphere of argon purified by contact with zirconium turnings. After this treatment the specimen was still silvery white in appearance. All specimens were electro-polished in a solution of 50 cc of perchloric acid in 1000 cc of glacial acetic acid at a current density of 0.6 amp/cm² after initial grinding and polishing on emery paper.

The unannealed specimens (Fig. 6) illustrate the general structure of the weld zone, the cast structure present in the molten zone, the acicular structure typical of zirconium heated above the α-β transformation temperature of 862° C as mentioned in the determination of the temperature gradient, the equiaxed structure of the annealed (but not heated above the transformation temperature) zone, and the normal worked structure of the original sheets.

The annealed specimens (Fig. 7) illustrate the form in which the carbide is present, with some possible bearing on the resistance to corrosion. The carbide in the molten zone, although exactly similar in appearance to that in the other three zones, is much more finely dispersed, and it would appear that the carbide content of

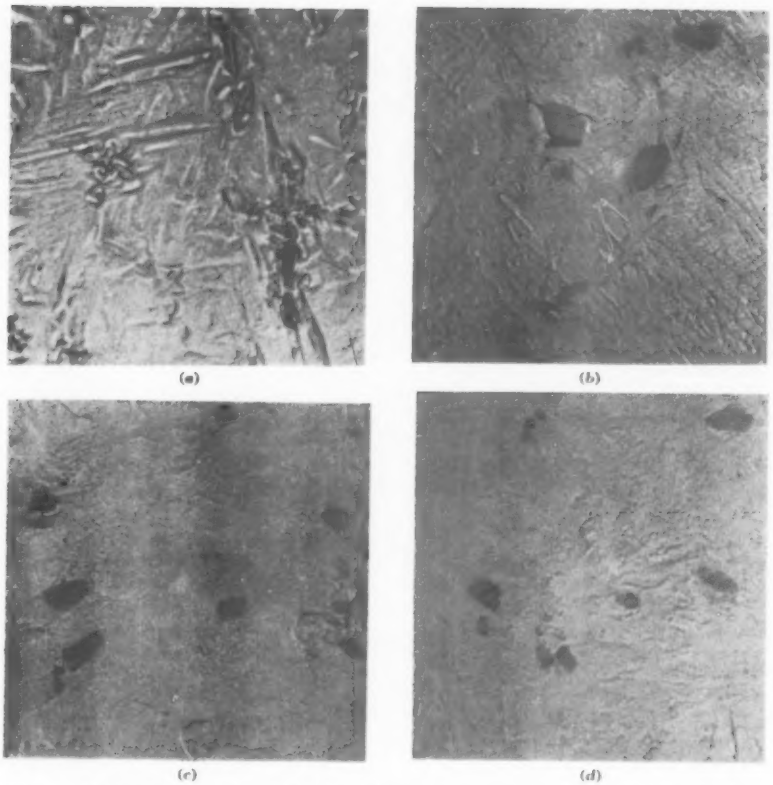

Fig. 6 Photomicrographs of the four zones of an unannealed weld in zirconium sheet. Electropolished in acetic acid/perchloric acid. × 500

(a) The molten zone, showing typical cast structure. (b) The acicular structure characteristic of zirconium annealed above the α-β transformation temperature. (c) The equiaxed structure typical of zirconium annealed below the transformation temperature. (d) The zone unaffected by welding—the normal worked structure.

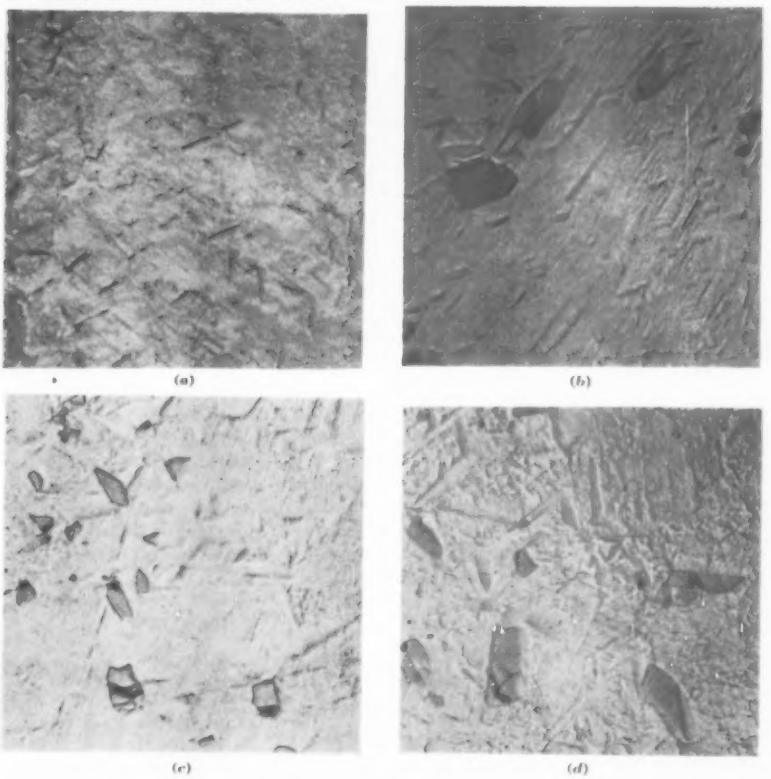

Fig. 7 Photomicrographs of the four zones of an annealed weld in zirconium sheet. Electropolished in acetic acid/perchloric acid. × 500

(a) The molten zone of the weld illustrating the fine particle size and dispersion of the carbide. (b) A similar area to that shown in Fig. 6 (b). The large grains of carbide and large zirconium grains are illustrated. (c) The equivalent area to Fig. 6 (c). The carbide grains are similar to those in the other two unmelted zones, the size of the zirconium grains is intermediate. (d) The nonheat-affected zone. The grain size of the zirconium is smaller than in any of the heat-affected zones.

the molten zone is rather less than that of the others. The progressive decrease in the grain size of the zirconium from the molten to the non-heat-affected sheet is also shown.

It can now be concluded that impurities in the argon, including contamination due to inadequate protection, is not the only factor of importance in the production of ductile welds in zirconium, and that the time factor is of equal, if not greater, importance. It is possible to produce ductile welds on thin sheets of zirconium in the protective atmosphere provided by the use of the ceramic hood around the electrode to direct the stream of argon on to the hot zone if the back of the weld is suitably protected, but purer argon than at present commercially available in this country is necessary to weld zirconium slab or plate without increasing the hardness above that of the original metal. Between the extremes of thin sheets and the slab or plate lies the range of thickness which is most important and useful, and it is to these gauges of sheet that most attention has been paid in developing welding techniques capable of practical application. Ductile welds can be made in these sizes using commercial argon, but the conditions demand complete shielding of the arc.

It was realized at the outset that the design of a universal hood would be impracticable and so attention was directed to designs likely to be of use for general applications. For example, it has been proved that ductile butt welds can be made in zirconium sheet by using a hood with a rubber seal around the bottom, the rubber seal being pressed against the sheet. The torch was fitted in the same manner as in the box and the hood was moved along the work as welding progressed. This hood is illustrated in Fig. 8.

In order to maintain a positive pressure of argon inside the hood it is necessary to have a subsidiary argon flow of 5 cfh into the hood in addition to the normal flow of 16 cfh through the torch. Positive pressure within the hood is essential to prevent air diffusing into it with consequent embrittlement of the welds. Such a method can be used to advantage in welding long seams such as may be required in the construction of tanks, and two hoods, used back to back against each other, would effect considerable economies when welding vertical seams in

thick sheet. Welding would be almost twice as fast, and it would not be necessary to protect the back of the welds with a stream of argon.

Figure 9 shows a further modification of the box, arranged for welding moderate-size pieces of almost any shape. In principle, construction follows the lines already described, but the box is mounted between two laboratory-type retort stands on which it can be raised or lowered to accommodate the parts to be welded. The arc is level with the bottom of the perspex sides. A curtain of polythene film encloses the work, the curtain being secured with cellophane tape to make an airtight enclosure, and the hood so formed is flushed with argon before use. The inlet tube for the subsidiary supply of argon can be seen in the photograph. For particularly awkward applications it would be possible to construct a hood of this type but incorporating rubber gloves through which to manipulate the torch and filler rod. A further development of this principle would be a cabinet on the lines of a sandblasting cabinet, but the size of such a structure would have to be limited to suit the work in hand so as to avoid excessive consumption of argon.

Four modifications of the original box developed for the welding of zirconium have been described. These give an indication of the conditions which have to be met when the design of a protective hood for a specific application is being considered.

The ability to withstand cold work has been used in these experiments merely to demonstrate the ductility of the welds, but the ductile properties of properly made welds in zirconium suggest interesting possibilities which, although not necessarily adaptable to large-scale production, might have uses for specific applications. Thick sheets of zirconium could be welded together before rolling to strip by the customary strip-rolling procedure. The process could be used in the manufacture of "seamless" tube by welding rolled sheet and then drawing down in the usual manner. By a modification of the tube-drawing application zirconium coatings could be put on other materials in the same way as insulated cables are sheathed with aluminum.

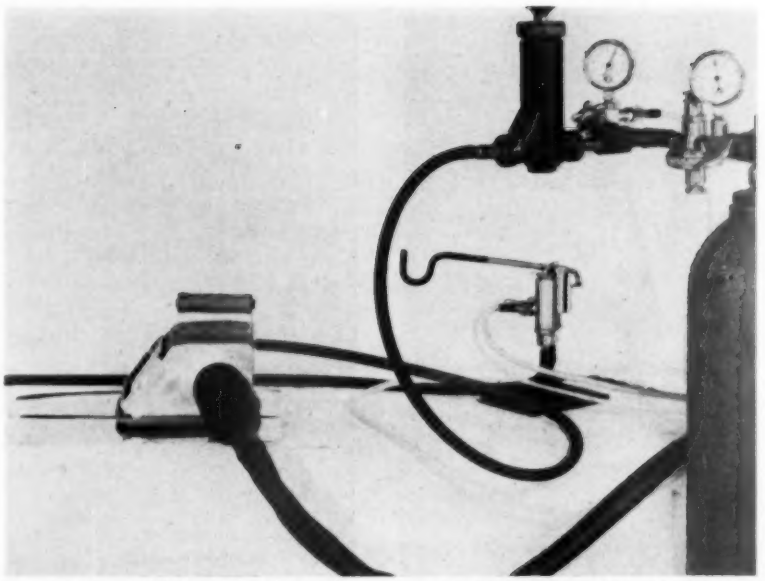

Fig. 8 Welding hood for welding seams in flat sheet or large tanks

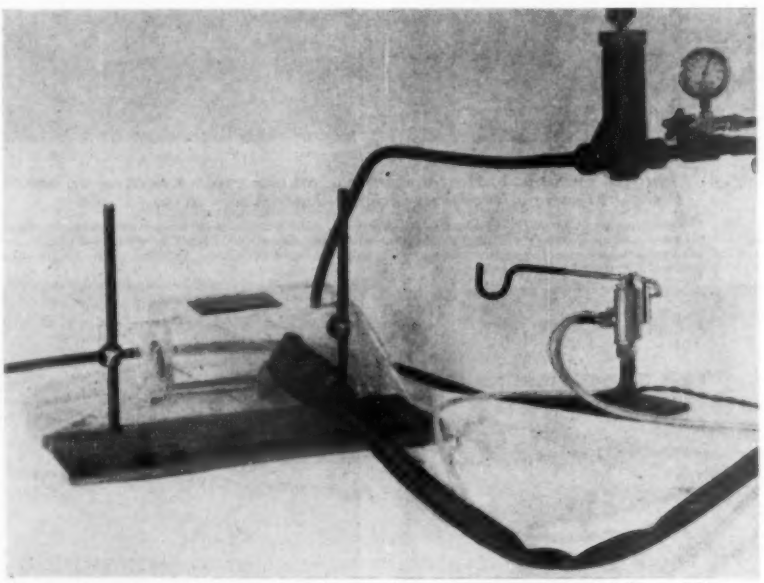

Fig. 9 Perspex welding hood with polythene envelope designed for welding an assortment of shapes of moderate size

SUMMARY

It has been established that the conditions necessary for the production of ductile welds in zirconium are:

1. For welds in zirconium sheet of the order of 0.030 in. or thinner, welds made with direct current are definitely superior to those made with alternating current. When direct current is used for welding with the unmodified torch, the only additional protection needed is the argon stream on the back of the weld.

2. In welding zirconium sheet in thicknesses up to the order of 1/4 in. it is necessary to shield the work in a much more exacting manner to exclude all traces of air from the weld zone. It is not, however, necessary to purify the argon.

3. To ensure ductile welds in sheets thicker than 1/4 in., the welds must be made in an atmosphere of pure argon. (This has been confirmed by reports indicating the need for stringently pure argon when melting zirconium for ingots by an arc struck between a tungsten electrode and the zirconium in a protective atmosphere of argon.)

A most important observation arising from this investigation is that the corrosion resistance properties of properly made welds are such that they can be expected to outlast the parent sheet under conditions of corrosive attack.

As the welding properties of titanium are in many respects similar to those of zirconium it can be said, in conclusion, that the recommendations made for the welding of zirconium should apply almost equally to the welding of titanium.

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Relation of Preheating to Embrittlement and Microcracking in Mild Steel Welds

Some evidence indicating that benefits of preheating are often realized through the deceleration of low-temperature cooling and the consequent prevention of microcracking

by A. E. Flanigan and T. Micleu

Abstract

This paper relates an extension of earlier studies concerned with a type of embrittlement affecting mild steel arc welds which are allowed to cool too rapidly through the low-temperature range following welding. It describes an effort to determine the extent to which the well-known benefits of moderate preheating are related to the deceleration of cooling in the low-temperature range. In the case of welds which normally exhibit microcracking when deposited at room temperature, it was found that preheating produced marked benefits in terms of bend test ductility. These benefits were closely associated with the elimination of microcracking. In the case of welds not subject to microcracking when deposited at room temperature, preheating was found to be of considerably less benefit. The investigation was limited principally to considerations of weld metal behavior. Less attention was devoted to the heat-affected zone.

1. INTRODUCTION

THIS paper describes a recent investigation concerned with the role of microcrack-prevention in connection with the benefits induced by the preheating of E6010 welds in mild steel.* This introductory section will be devoted to a brief review of the microcracking phenomenon and to an explanation of the basis for suspecting that the beneficial effects of preheating may often stem from the incidental prevention of microcracking.

In recent years it has been reported that too rapid cooling following the arc welding of mild steel may produce fine-scale fissuring of the deposited metal with adverse effects on various mechanical properties.[1-5] Detection of such fissures requires the microscopic examination of carefully polished sections. Once formed, the defects are not susceptible to healing by thermal treatment. It is believed that microcracking ordinarily occurs only after the cooling weld has reached a temperature range below that usually associated with the decomposition of austenite in mild steel. While the mechanism of formation is not altogether clear, it seems certain that the hydrogen content of the weld is a factor of prime importance. Welds deposited with "low-hydrogen" electrodes possess remarkable resistance to microcracking. In welds made with the more popular hydrogen-rich varieties it appears that microcracking may be prevented by measures which insure sufficiently slow cooling in the low-temperature range.

In welding practice, preheating has long been recognized as an effective method of preventing embrittlement in difficult-to-weld applications. It is most commonly employed in the welding of the more hardenable steels but can often be used to advantage in work on mild steel as well. (This paper is concerned only with the latter usage.)

While the effectiveness of preheating has been abundantly apparent, there has been cause to feel that the reason for its effectiveness has not been altogether clear. The usual explanations have attributed the benefits to elevated-temperature effects concerned either with the transformation of austenite in the heat-affected zone or with a general broadening of the latter region. In the light of such explanations it has been disturbing to note in welding practice that moderate preheating is surprisingly effective in the case of mild steel welds. In a California shipyard, for instance, it was reported that a disproportionate number of embrittlement problems affected welds deposited on the night shift when the temperature was somewhat lower than during the day. The problems were generally solved by employing heating torches "to take the chill off the work" before welding. It is difficult to believe that the small alterations in elevated-temperature conditions produced by mild preheating could be of such decisive benefit. On the other hand, one might expect even mild preheating to exert a strong influence on the cooling rates at lower temperatures. Since it is thought that microcracking ordinarily occurs as a result of too rapid cooling in the latter range, one is inclined to wonder if the benefits of preheating may not often be realized, in part at least, through the prevention of microcracking. Suggestions to this effect have been expressed or implied by Bland and by Rollason and Roberts and have undoubtedly occurred to others who have studied microcracking.

2. THE METHOD OF INVESTIGATION

To determine directly the extent to which preheating has been responsible for the prevention of microcracking in welding practice would, of course, require considerable effort. It would be desirable to study a number of typical instances in which preheating had been found essential for satisfactory welding. In each instance it would be necessary to compare a preheated weld with one made without preheating. If microcracking were found to be characteristic of the nonpreheated welds but were seldom encountered after preheating, an important relation would be indicated.

While recognizing the desirablity of such a procedure, the authors were forced to employ a less ambitious and less satisfying method. The present investigation was limited to the study of a single in-

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stance in which microcracking was known to occur in the absence of preheating. In selecting this instance an effort was made to choose welding conditions which would be of practical interest and which at the same time would permit the use of small laboratory specimens. The selection was made on the basis of an earlier study.

Figure 1 has been reproduced from reference 5 to assist in explaining the method of selection. It refers to a series of notched-bend tests on ASTM A285-C specimens bearing air-cooled E6010 bead-on-plate welds of various lengths. The dimensions of the specimen are shown in the figure. The bend tests were conducted at −100 and at 70° F. It will be noted in Fig. 1 that in both cases the specimens having the shorter welds failed at low values of bend angle while the longer welds achieved considerably greater values. It may also be seen that a rather abrupt transition in bend test behavior occurs in the region of a 4-in. weld length. As related in reference 5, examination disclosed that no microcracks were present in the 5-in. welds but that many occurred in those of the 2½-in. length. The 4-in. welds appeared to constitute a borderline case.* Thus it appeared that the inferior performance of the short welds was a manifestation of the adverse influence of microcracking.

On the basis of this evidence, it was decided in the present investigation to use a specimen consisting of a 3-in. weld on a piece of ¾-in. plate having the 4- by 9-in. dimensions employed in the earlier work and indicated in Fig. 1. Such a specimen was expected to contain microcracks and to behave brittlely in the absence of preheating. It was also thought to be of direct practical interest since short welds are commonly used (as in intermittent fillets, in the welding of small attachments to large structures, in repair welding, etc.). Moreover, the velocity of low-temperature cooling of such a weld is comparable to that some times encountered in longer welds or more massive work.

The investigation included the following phases. Three-inch welds were deposited at preheating temperatures ranging from 70 to 300° F. They were subjected to bend tests at 70° F, to examinations for microcracking and to studies of microstructure and hardness. In addition, the cooling rates following welding were carefully measured. Some full-length 9-in. welds were treated in similar fashion to determine the response of specimens not subject to microcracking in the absence of preheating. The various indications were then examined for correlations.

The A285-C plate used in the preparation of specimens was obtained from the same heat as had been employed earlier in the work of references 4 and 5. Chemical analysis showed 0.19% C, 0.33% Mn, 0.07% Si, 0.03% S and 0.015% P. Before welding, the mill scale was ground away from the paths of the welds. Preheating at temperatures up to 212° F was accomplished in heated water while that at 300° F was done in air in a furnace. The welds were deposited with 3/16-in. E6010 electrodes at 170 amp, 25 v and an arc speed of 7.7 ipm. After the completion of welding, the specimens were placed on a wooden surface, welded side upward, to cool in air at 70° F.

The results of the various studies are described in the following sections.

* The occurrence of microcracks in the shorter welds appeared to result from their more rapid low-temperature cooling. Cooling rates in the low-temperature range are strongly dependent on the ratio of specimen size to heat input. This ratio may be controlled by varying the length of the weld on a specimen of fixed size, a decrease in weld length producing an increase in cooling rate.

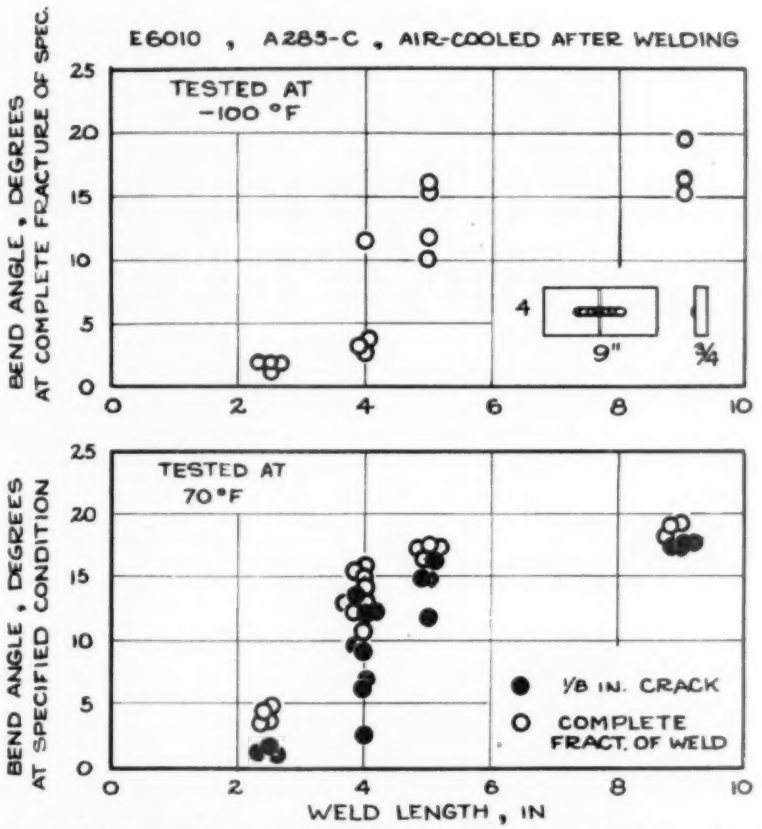
E6010 , A285-C , AIR-COOLED AFTER WELDING
TESTED AT −100 °F
BEND ANGLE , DEGREES AT COMPLETE FRACTURE OF SPEC.
4
9"
¾
TESTED AT 70°F
BEND ANGLE , DEGREES AT SPECIFIED CONDITION
⅛ IN. CRACK
COMPLETE FRACT. OF WELD
WELD LENGTH , IN

Fig. 1 Effect of weld length on E6010 bend test behavior at 70 and at −100° F

3. BEND TEST RESULTS

The specimens used in the bend tests were notched and tested in the manner employed earlier in the work of Fig. 1. The notch consisted of a transverse U-shaped groove, of 1/16 in. radius, milled across the entire width of the specimen to a depth 0.020 in. below the plate surface. In the tests, which were performed either 5 or 6 days after welding, the specimen was bent as a centrally loaded simple beam with the weld in tension. The supports were spaced 6 in. apart.

During testing the load was applied without interruption at a rather slow cross-head speed (0.7 ipm) to allow continuous observation of the base of the notch via a suitably placed mirror. Observations were made with the unaided eye at a distance of about 1 ft. As in the earlier work, the first indications of fracture were observed to occur in the weld metal itself rather than in the heat affected zone or in the unaffected plate. Since the testing temperature was sufficiently high to render the specimen rather resistant to crack propagation, fracture growth progressed in leisurely fashion. In no case had the fracture entirely traversed the width of the specimen before the limit of the fixture had been reached at a bend angle of 40 deg. This, of course, necessitated the adoption of an arbitrary criterion for failure. This section describes the results in terms of a single criterion, the bend angle required to produce a crack length of 1/8 in. at the base of the notch. For reasons described in Section 9 this criterion was considered to be of special interest. Section 9 also describes some additional bend test data.

In terms of the 1/8-in. criterion, Fig. 2 shows the effects of preheating on both the 3- and the 9-in. welds. It may be seen that in the absence of preheating (i.e., with a preheating temperature of 70° F) the performance of the 9-in. welds, averaging about 18 deg of bend angle, is far superior to that of the 3-in. group which averages somewhat less than 4 deg.

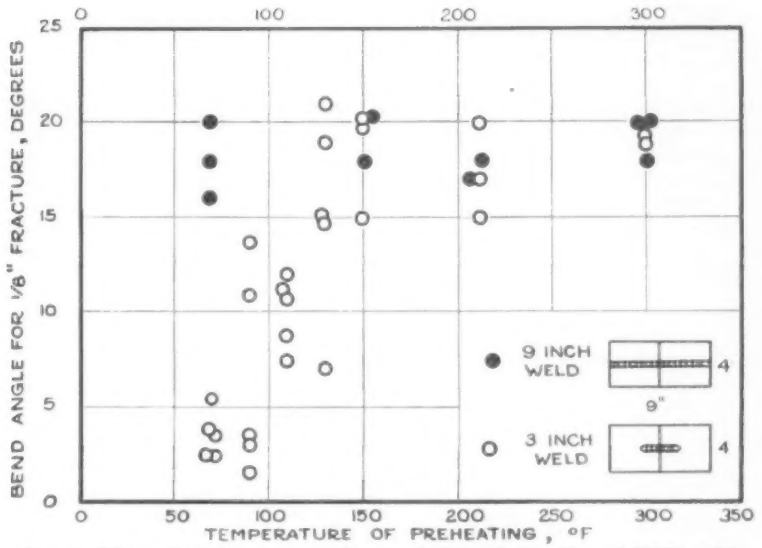

Fig. 2 Effect of preheating on the notched-bend ductility of E6010 welds

This behavior is, of course, as would have been anticipated on the basis of Fig. 1.

It will also be noted in Fig. 2 that the performance of the 9-in. welds is improved little if any by preheating at temperatures up to 300° F. That of the shorter welds, however, is greatly improved. With regard to the latter group, it is of interest to note the rather sharp transition in bend test behavior which occurs in the range of preheating temperatures between 90 and 130° F. Specimens preheated at 130° F approach the performance level characteristic of the 9-in. group. At preheating temperatures above 150° F no further improvement is apparent and the behavior of the 3-in. welds appears to be essentially the same as that of the 9-in. variety. The abruptness of the transition is noteworthy since it resembles the sharp changes in bend test behavior which were encountered under other conditions in earlier work and which were found at that time to depend on the presence or absence of microcracking.

4. OBSERVATIONS ON MICROCRACKING

To determine whether the bend test behavior of the 3-in. welds could be correlated directly with microcracking, some of the welds were subjected to microscopic examination. (Methods for detecting microcracks are discussed in reference 5.)

The examinations were made on the weld's longitudinal plane of symmetry. This plane was exposed by means of saw cuts and then was electropolished in a chromium trioxide-acetic acid solution. Examination of the polished surface was made at 200 × without etching. Two groups of specimens were studied. In the first case, samples were removed from specimens which had been used earlier in the bend tests. In the second, they were cut from nonbent specimens.

Part A of Fig. 3 shows the location of samples taken from previously deformed bend-test specimens. The orientation of the plane of polish is illustrated in Part C of the same figure. Each of the samples was polished and examined by two different observers who counted all of the microcracks which they could discern. The samples were studied in random order and their histories were not revealed to the observers until after the examinations had been completed. The results of the individual crack counts are shown in Table 1. As may be seen, microcracks were found by each observer in the 3-in. welds preheated at 90° F. In no case, however, did either observer find even a single microcrack in those preheated at 130° F.

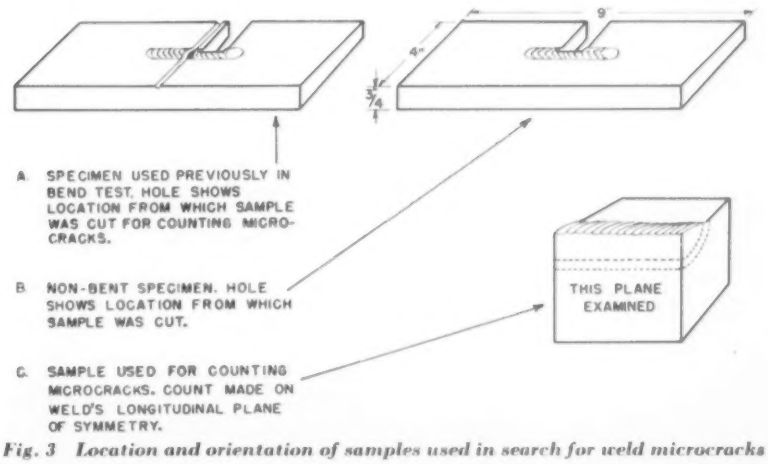
9"
4"
3/4
A. SPECIMEN USED PREVIOUSLY IN BEND TEST. HOLE SHOWS LOCATION FROM WHICH SAMPLE WAS CUT FOR COUNTING MICRO-CRACKS.
B. NON-BENT SPECIMEN. HOLE SHOWS LOCATION FROM WHICH SAMPLE WAS CUT.
C. SAMPLE USED FOR COUNTING MICROCRACKS. COUNT MADE ON WELD'S LONGITUDINAL PLANE OF SYMMETRY.
THIS PLANE EXAMINED

Fig. 3 Location and orientation of samples used in search for weld microcracks

Table 1—Observations on Microcracking in Previously Bent Specimens

Preheating temperature, ° F.	*Number of fissures observed at 200 × in ²/₈-in. length of weld by—*	
	Observer A	*Observer B**
90	6	3, 6, 7
90	4	2, 3, 4
90	6	3, 3, 0
90	5	3, 4, 2
90	5	1, 1
130	0	0, 0
130	0	0, 0
130	0	0, 0
130	0	0, 0
130	0	0, 0

* Observer B examined each specimen several times.

Since the samples of Table 1 had been obtained from previously bent specimens, some of them had undergone plastic deformation prior to examination. This, one might suppose, could have enhanced the prominence of microcracking in deformed portions and might have caused the appearance of fissures in regions where none would have been noted before deformation. In view of this possibility, a second set of samples was cut from specimens which had not been notched or bent. These samples were taken from the location indicated in Part B of Fig. 3. They were examined by two observers one of whom was "Observer B" of Table 1.* Their findings are shown in Table 2 where, it will be seen, the indications are similar to those of Table 1. Again the 3-in., 130° F welds appear to be essentially free from microcracking while those welded at 70 and 90° F exhibited conclusive indications of cracking.

The 90 and 130° F welds are of particular interest since they bracket the transition region of Fig. 2. Comparison of this evidence on microcracking with the bend-test results indicates that inferior performance in Fig. 2 is indeed closely linked to the occurrence of microcracking.

* The second, listed as "Observer C" in Table 2, used a somewhat different method of specimen preparation believing that it tended to be more effective in revealing microcracks. He employed a sequence consisting of electropolishing, etching in nital and re-electropolishing.

Table 2—Observations on Microcracking in Nonbent Specimens

Preheating temperature, ° F.	*Number of fissures observed at 200 × in 1-in. length of weld by* Observer B*	Observer C
70	15, 18	
70	7, 8	
90	8, 6, 7, 10	21
90	7, 4, 0, 5	1
90	4, 2, 4, 2	10
90	3, 12, 1, 14	9
130	0, 0	0
130	0, 0	0
130	0, 0	1
130	0, 0	1

* Observer B examined each specimen several times.

All of the microcracks reported in Tables 1 and 2 occurred in the weld metal. In no case were any found in the heat-affected zone. In appearance, the microcracks were similar to those illustrated by photographs in reference 5.

5. HARDNESS STUDIES

Recognizing that the favorable influence of preheating as manifested in Fig. 2 was probably linked with the prevention of microcracking, it was of course, wondered if preheating might not have been beneficial in other ways as well. For this reason an attempt was made to determine whether appreciable changes in hardness were induced by preheating at temperatures up to 300° F.

The hardness studies were made with a Tukon apparatus employing a Knoop indenter and a 300-g load. The specimens, which had not been subjected to bending, included welds of the 3-in. variety preheated at 70, 130 and 300° F and some 9-in. welds preheated at 70° F. Each of these four conditions was represented by several separate welds. A sample was sawed from the mid-length region of each weld and was prepared for examination by electropolishing on a face normal to the axis of the weld. Each sample was then subjected to several hardness traverses along the centerline of the section.

The results of the hardness studies are shown in Figs. 4 to 7. At the outset it will be noted that the data exhibit a disconcerting degree of scatter in spite of the rather large number of determinations which was made. To some degree, the scatter is associated with readings made on individual welds. To a greater extent, however, it reflects variations among the several welds representing a given condition. To indicate the magnitude of the latter source, a separate symbol has been used for each sample in a given figure.

Despite the uncertainties which attend the scatter, the following observations are believed to be justified.

(*a*) In general, the greatest values of hardness are seen to occur in the weld metal or at the fusion line. This is not surprising since it has been observed in earlier work with mild steel that, even in the absence of microcracking, it is the weld metal which generally exhibits the least capacity for deformation.

(*b*) If one considers the hardness of weld metal alone, the average values are found to be approximately 222, 238 and 222 for 3-in. welds preheated at 70, 130 and 300° F, respectively, and about 222 for the 9-in. welds preheated at 70° F. There would appear to be no reasonable correlation between these values and the bend test data of Fig. 2. If, instead of the overall averages, one considers only a group of the larger hardness values for each condition, correlation is again lacking. While such indications are not conclusive, it would seem probable that the benefits of preheating in Fig. 2 arise less from influences affecting weld metal hardness* than from those associated with microcracking.

(*c*) If one considers only the hardness values at the fusion line, there again would seem to be little if any correlation between hardness and bend-test performance. In this connection it must be noted that the prominent group of high values in Fig. 4 is associated with only a single specimen (indicated by the open triangles) and consequently cannot be considered typical. In any case, it will be recalled that the fractures in the bend tests were observed to occur in the weld metal rather than at the fusion line.

* Hardness-affecting influences would, of course, include those affecting the mode of austenite decomposition. They might also include factors associated with the precipitation of carbides, nitrides or perhaps other phases from supersaturated ferrite.

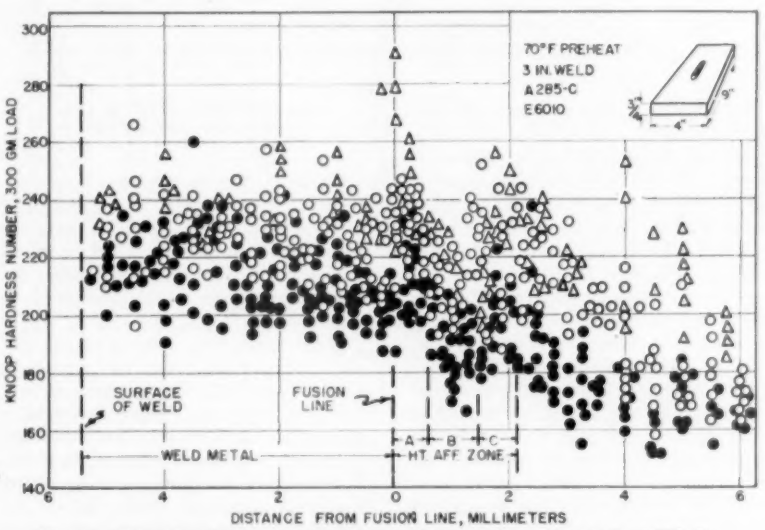

Fig. 4 Microhardness distribution in 3-in. weld preheated at 70° F
(Each type of symbol refers to the data obtained from an individual weld)

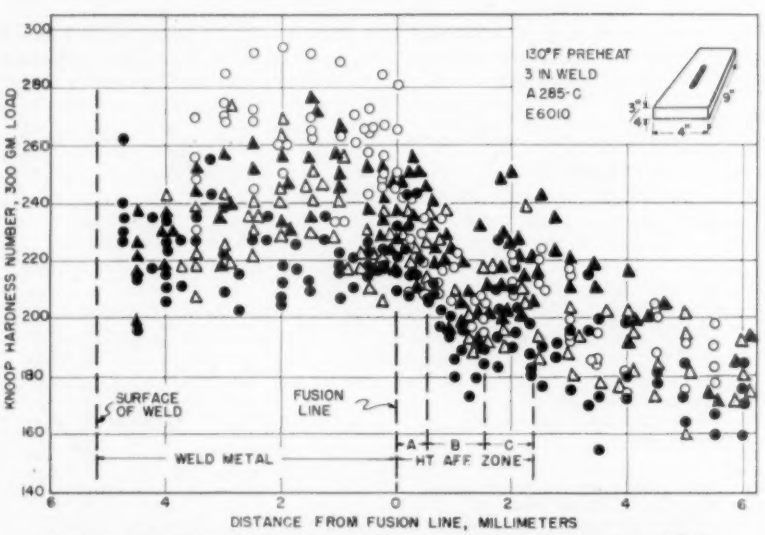

Fig. 5 Microhardness distribution in 3-in. weld preheated at 130° F
(Each type of symbol refers to the data obtained from an individual weld)

6. BROADENING OF THE HEAT-AFFECTED ZONE

The samples employed in the hardness studies were also used in an attempt to determine whether alterations in microstructure had been produced by preheating. No changes were observed, however, except for some broadening of the heat-affected zone.

The dimensions of the heat-affected zone are indicated for each condition in Figs. 4 to 7. In the figures "Zone A" represents the region of grain coarsening, "Zone B" denotes the region of refinement and "Zone C" represents the region of partial but incomplete austenitizing. The dimensions shown in each figure were obtained by averaging the individual values exhibited by the several welds. The measurements were made along the centerline of a transverse cross section as in the case of the hardness traverses.

It will be noted in Figs. 4 to 7 that preheating induces appreciable increases in the depths of the heat-affected regions. The total depths (i.e., the depths for A, B and C combined) appear to be about 2.1, 2.4 and 2.9 mm for 3-in. welds preheated at 70, 130 and 300° F respectively. The value for the 9-in., 70° F weld is about 2.4 mm. It is difficult to estimate to what extent, if any, this broadening contributes to the abrupt transition in Fig. 2. One suspects, however, that its role is probably a minor one in comparison with that of microcrack-prevention. This suspicion is based on the observation that the fractures reported in Fig. 2 originated in the weld metal itself rather than in the heat-affected zone. In addition, Fig. 2 indicates that 300° F preheating of the 3-in. weld induced little if any improvement over that obtained at 130° F. The broadening of the heat-affected zone, however, was certainly greater.

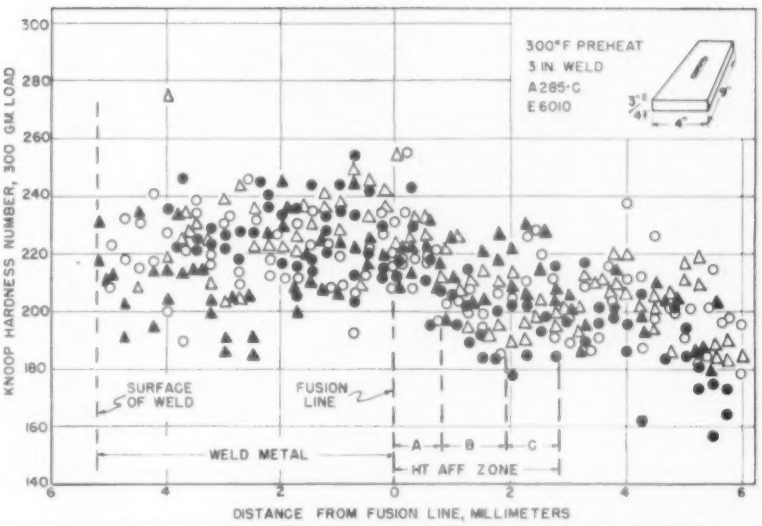

Fig. 6 Microhardness distribution in 3-in. weld preheated at 300° F
(Each type of symbol refers to the data obtained from an individual weld)

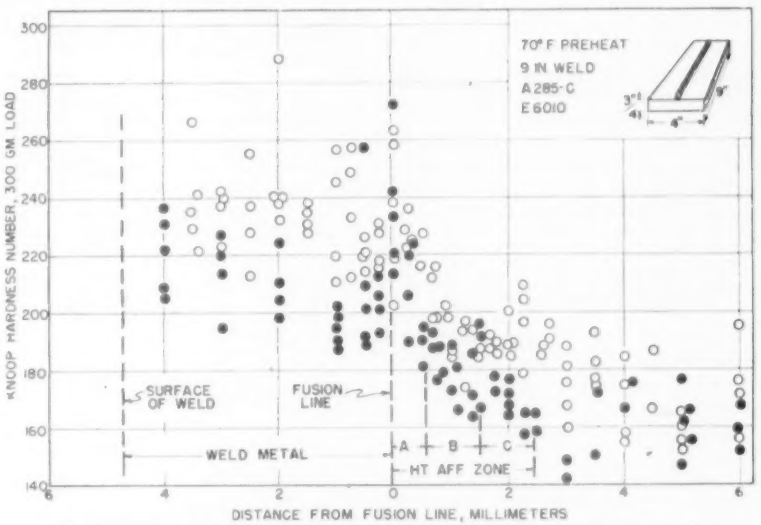

Fig. 7 Microhardness distribution in 9-in. weld preheated at 70° F
(Each type of symbol refers to the data obtained from an individual weld)

7. COOLING RATE DETERMINATIONS

Since the principal function of preheating is probably to alter the velocity of cooling, it was considered desirable to report the actual cooling histories of some of the preheated welds. For this reason some specimens were welded in the usual manner and their cooling rates were determined with the aid of a high-speed recording potentiometer. During the welding of a given specimen a 28 gage chromel-alumel thermocouple was inserted into the molten weld at midlength. The couple was allowed to remain during solidification and subsequent cooling. The conditions studied included 3-in. welds preheated at 70, 130 and 300° F and 9-in welds preheated at 70 and 300° F.

The cooling curves are shown in Fig. 8 where each curve represents the average of at least three determinations. Zero time on the horizontal scale is defined arbitrarily as the instant at which the cooling weld was observed to pass through a temperature of 1600° F.

In Fig. 8 it is of interest to compare the cooling curves for the 3-in. welds preheated at 70 and 130° F since these represent conditions bracketing the transitions in bend test behavior and in microcracking tendency. It will be noted that at the higher temperatures there is little difference in the paths of these curves. For example, the 3-in. weld preheated at 130° F requires about 4½ sec to cool to 1000° F while the weld preheated at 70° F requires about 4 sec. This agreement at elevated temperatures is, of course, to be expected in the case of such mild preheating. At lower temperatures the difference is considerably greater. It may be seen that the 130° F weld required about 60 sec to reach 300° F while the 130° F weld reached the same temperature in only 40 sec. In the same order, the times required to reach 200° F were about 300 and 110 sec. This comparison illustrates the principle that mild preheating, while exerting little influence on elevated-temperature cooling, is capable of producing large alterations in the rapidity of low-temperature cooling. It also suggests that the absence of microcracks in the 3-in., 130° F welds is probably related to slower cooling at the lower temperatures. (Direct verification of the latter suggestion is presented in the next section.)

In Fig. 8 it is also of interest to compare the 3-in. 130° F curve with the

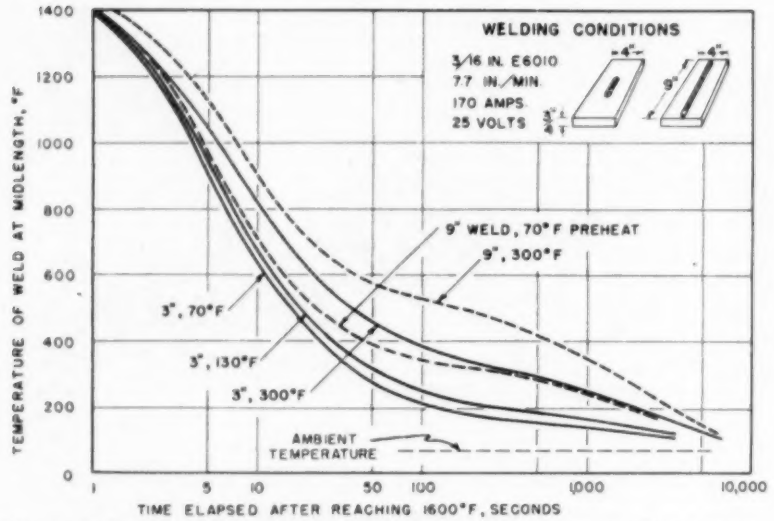

Fig. 8 Influence of weld length and preheating temperature on cooling history

three curves which lie to the right, namely those for the 3-in. 300°F, 9-in. 70°F and 9-in. 300° F welds. Cooling, especially at the lower temperatures, is considerably slower in the welds of the latter group. They require from 2000 to 3200 sec to reach 200° F as opposed to only 300 sec for the 3-in.,130° F weld. Yet, as has been seen earlier, the much slower cooling would appear to have produced little additional benefit in terms of bend test performance or hardness.

8. THE TEMPERATURE OF MICROCRACK FORMATION

This section describes some supplementary evidence which directly emphasizes the importance of low-temperature cooling in the present investigation.

We shall first refer to some tests which indicate that most of the microcracking of the nonpreheated 3-in. welds occurred at temperatures below 212° F. Twelve specimens were welded in the usual manner at 70° F and then were allowed to cool in air until various mid-length temperatures had been attained as judged by previously derived cooling curves. Two of the specimens were allowed to cool to each of the following temperatures: 370, 300, 250, 212, 150 and 70° F. Normal air cooling was then abruptly interrupted by plunging the specimens into a nitrate-nitrite salt bath at approximately 650° F.* Five minutes later they were removed from the salt bath and were allowed to cool in air to room temperature. Subsequently they were examined for the presence of microcracking. (The examiner, "Observer D," employed the technique of Observer C of Table 2. See footnote in Section 4.) The results of the examination are shown in Table 3.

Table 3—Observations Concerning the Temperature of Microcrack Formation in Air-Cooled 3-In. Welds Deposited at 70° F

Temperature at which air cooling was interrupted, ° F.	*Number of fissures observed at 200 × in 1-in. length of weld after interruption of cooling (Observer D)*
370	0
370	0
300	0
300	0
250	1
250	0
212	0
212	2
150	9
150	30
75	14
75	12

It will be seen that no cracks were found in the welds subjected to interruption of cooling at 370 and 300° F. A small and perhaps indecisive number was noted in the welds interrupted at 250 and 212° F while numerous cracks were observed in those interrupted at both 150 and 70° F. On the basis of these observations it was concluded that the microcracking which characterizes the uninterrupted air cooling of 3-in. welds occurs in the main at temperatures below 212° F.

The conclusion just cited is consistent with the earlier indication of Fig. 8 that the cooling rates of the 3-in. welds preheated at 70 and 130° F differ most markedly in the low-temperature range. Accordingly, it would appear that it is the slower cooling in this range which is mainly responsible for the absence of microcracking in the 130° F welds. As an alternative to such a belief, however, it might be imagined that the relatively slight difference at elevated temperatures is more significant. Conceivably, the latter might permit the completion of some high-temperature process rendering the weld immune to subsequent cracking as it traverses the low-temperature range. That such is not the case is indicated by the additional tests described in the next paragraph.

A group of six 3-in. welds was deposited at 300° F. The use of this preheating temperature, of course, insured that elevated-temperature cooling was even slower than that induced by preheating at 130° F. The specimens were allowed to cool in air until certain desired temperatures had been reached. They were then quenched in water at 70° F to insure rapid cooling below the temperature of interruption. Later the welds were sectioned and were examined for microcracks.* Two which had been quenched from 500° F were found to contain 85 and 107 microcracks in a 1-in. length. Two interrupted at 400° F contained 15 and 12 while a pair interruped at 300° F exhibited 0 and 0. It appeared, therefore, that, even in these specimens preheated at 300° F, the slowing of elevated-temperature cooling was not in itself sufficient to insure immunity to microcracking upon subsequent rapid cooling. Not until a temperature somewhat below 400° F had been reached was such immunity realized.

As mentioned earlier, it seems rather certain that the mechanism of microcracking is one which involves the adverse influence of hydrogen. The retarded cooling induced by preheating probably permits the favorable redistribution or partial removal of this element before the cooling weld reaches temperatures at which cracking may occur. Whatever may be the exact nature of the mechanism, it seems likely that immunity to cracking might be achieved by sufficiently long exposure to elevated temperatures during cooling. Under the conditions ordinarily encountered in welding, however, the duration of elevated-temperature exposure following welding is necessarily of short duration unless high preheating temperatures are used. It is for this reason perhaps that the velocity of low-temperature cooling is often decisive with respect to microcracking. It is fortunate that the latter may be controlled so readily by means of moderate preheating.

9. ADDITIONAL REMARKS ON THE BEND TESTS

Up to this point, frequent reference has been made to Fig. 2 which describes bend test performance in terms of a rather arbitrary criterion, the bend angle required to produce a $\frac{1}{8}$-in. crack. This

* It was desired to learn whether or not microcracking had occurred before the interruption of cooling. Once formed, microcracks are not removable by such reheating.

* All of the counts mentioned in this paper were made on a section of the type shown in Part C of Fig. 3.

section is concerned with the significance of such a criterion and with some other observations made during the bend tests.

As noted in Section 3, fracturing was found to originate in the weld metal and since the specimens possessed considerable resistance to crack propagation, subsequent growth was sluggish. Following the attainment of the 1/8-in. crack length in a given specimen, an increase in bend angle was required to cause the fracture to completely cross the weld. During this stage of growth, extension appeared to be rather gradual. After the crack had reached the heat-affected zone, its progress was abruptly arrested and a considerable increase in bend angle (generally about 10 deg) was required before propagation was resumed. The heat-affected zone's superior resistance to crack propagation* has been noted frequently in other studies.[3-5]

In addition to determining the bend angle value associated with the appearance of a 1/8-in. crack, an attempt was made in each test to determine the larger value of bend angle required to produce complete fracturing of the weld and the still larger value associated with subsequent penetration of the crack-resistant region in the heat-affected zone. Figures 9 and 10 reveal the influence of preheating according to the latter criteria. While the indications of Fig. 9, concerned with complete weld fracture, are qualitatively similar to those of Fig. 2, the abrupt transition so prominent in the latter is less striking. In Fig. 10 the indication of such a transition is still weaker.

Had bending been continued, still larger angles would have been required to cause the fractures to traverse the entire 4-in. width of the specimen. Intermediate angles would have been required for values of crack growth corresponding to attainment of maximum load on the testing machine. Had either of the later criteria been employed, it seems probable that there would have been little indication of a transition and that the presence of weld metal microcracking might not have been suspected on the basis of bend test performance alone.

One, of course, may wish to ask if the incidence of microcracking and the use of the 1/8-in. criterion of Fig. 2 are of practical significance to fabricators and users of welded structures. In answering this question it is helpful to recognize that microcracks constitute a set of extremely sharp notches. Under some conditions the presence of even the sharpest notch may not interfere with the satisfactory performance of a structure. Under conditions favorable to crack propagation, however, microcracks may develop into macroscopic fissuring of the weld and the stress concentrations at the ends of the growing macrocracks may be sufficient to overcome the resistance of the heat-affected zone and of the entire structure. Under the influence of alternating stresses or impact loads, for instance, small cracks may sometimes lead to early failure. Even under static loading at ordinary temperatures the presence of small cracks may be undesirable in notch-sensitive steels. At lower temperatures the more notch-resistant steels may also be affected. Since such conditions are sometimes encountered in welded structures, it may not be wise to discount the importance of weld metal microcracking and bend test criteria of the sort employed in Fig. 2.

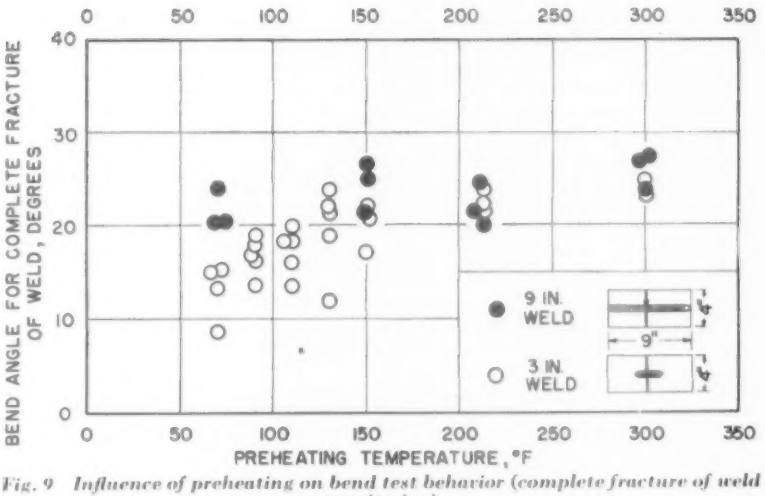

Fig. 9 Influence of preheating on bend test behavior (complete fracture of weld as criterion)

10. SOME LIMITATIONS OF THE STUDY

In considering the direct usefulness of the investigation certain limitations in scope should be borne in mind. Some of them are listed below.

(*a*) Only a single test, a particular version of the notched-bend test, was employed in the evaluation of mechanical performance. There are, of course, other useful tests which might have been employed and it is conceivable that some might have yielded different indications.

(*b*) In testing, attention was focused on the behavior of the weld metal rather than on that of the entire specimen. Different indications might have been obtained had

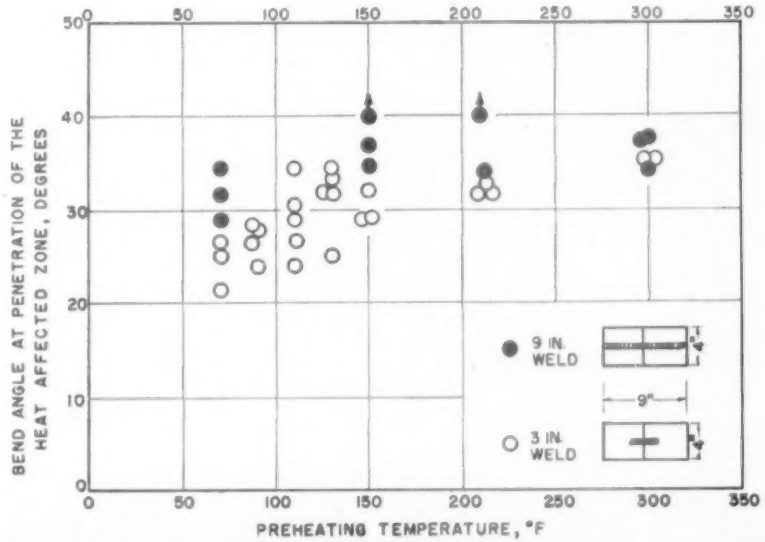

Fig. 10 Influence of preheating on bend test behavior (penetration of heat-affected zone as criterion)

* This crack-arresting ability of the heat-affected zone in room-temperature bend tests appears to be a property of the material itself rather than one of specimen geometry. It has also been observed in specimens from which the weld crown has been removed.

use been made of criteria which emphasize the over-all fracturing of the specimen. It is conceivable, for instance, that preheating might have improved the heat-affected zone's resistance to crack propagation. There is perhaps such an indication, though an indecisive one, in Fig. 10.

(*c*) Under the conditions employed it was found that preheating at 130° F was sufficient to prevent the formation of microcracks. It, of course, does not follow that the same temperature would have been adequate under more severe conditions. It will be recalled that the 3-in. welds represented a near-borderline condition with regard to the danger of microcracking. Had the welds been shorter, or had a lower rate of heat input been employed, a higher preheating temperature would undoubtedly have been required. It should also be remembered that in welding practice it is sometimes difficult to preheat an entire structure. Instead, recourse may be made to heating only along the path of the weld. Such a procedure is generally less effective with regard to the retarding of low-temperature cooling and hence a higher preheating temperature might be required. (If the benefits of preheating depended mainly on elevated-temperature phenomena rather than on those at lower temperatures, the width of the heated band would be of less importance.)

(*d*) In the present study only two types of specimens were employed. The 3-in. welds represented a borderline condition with cooling just sufficiently rapid to favor microcracking. On the other hand, the 9-in. welds represented a safer condition far removed from the borderline region. While preheating appeared to be of little benefit to the 9-in. welds, it is conceivable that such might not have been the case with welds closer to the borderline condition. In this connection, it would be of interest to study the behavior of 4-in. welds. In the absence of preheating, the latter do not exhibit microcracks although their bend-test performance is inferior (Fig. 1).

(*e*) Although efforts were made to consider the roles of factors other than microcrack-prevention in connection with the benefits of preheating, the efforts were by no means exhaustive. The hardness studies, for instance, were not as complete as might be desired. No attempt at all was made to assess the roles of certain other possible factors such as the reduction of transient and residual stresses.

11. SOME IMPLICATIONS

Despite the limitations just noted, it is believed that interesting implications stem from this investigation and from related studies (especially those of Bland and Rollason and Roberts) concerned with microcracking. Among them are the following:

(*a*) While microcrack-prevention may not be the sole factor involved in the benefits of preheating, it seems probable that it is often a major one.

(*b*) In the case of critical welds, it would seem wise to use preheating liberally when conditions are such as to promote rapid cooling in the low-temperature range. Rapid cooling is favored by low ambient temperatures, by low rates of heat input, by short weld lengths and by massiveness of the work. In combination these factors are, of course, additive.

(*c*) Perhaps certain mysterious failures of welded structures have in the past been associated with the presence of unrecognized microcracks which could have been avoided by suitable preheating.

(*d*) In terms of microcrack-prevention, it is possible to understand why even the mildest preheating has sometimes been found so effective in welding practice.

(*e*) Step-back procedures are known to be effective in combating weld metal cracking tendencies. Perhaps the benefit may sometimes be achieved through the incidental preheating and the consequent inhibition of microcracking.

(*f*) Since microcracking is irreversible in nature, it would seem that preheating may sometimes be preferable to postheating (assuming that a choice must be made).

(*g*) It is implied that preheating would seldom be required in the case of mild steel welds deposited with low-hydrogen electrodes since such welds are ordinarily resistant to microcracking.

(*h*) As suggested by Bland, there is the implication that misleading indications may stem from commonly used qualification procedures which allow the heating of specimens in boiling water before welding and between passes. Such practices might inhibit the formation of weld metal microcracks which otherwise would occur.

(*i*) In any research on the effects of preheating it would seem desirable to determine whether or not microcracking occurs under the conditions employed. In the past, failure to do so may have been responsible for apparent conflicts in the results obtained by investigators using different types of specimens. Under conditions favoring microcracking, one would, of course, expect preheating to yield marked benefits. Under less severe conditions (and this is commonly the case with small laboratory specimens) one would expect the effect to be relatively minor.

12. SUMMARY AND CONCLUSIONS

This investigation, concerned with the preheating of E6010 welds on mild steel, deals with the contribution of microcrack-prevention to the benefits induced by preheating. Two varieties of air-cooled bead-on-plate welds were studied. In the absence of preheating, one was subject to microcracking while the other was not. Both types were deposited at preheating temperatures ranging from 70 to 300° F and attempts were made to assess the effects of preheating on notched-bend performance, occurrence of microcracking, cooling history, hardness and depth of the heat-affected zone. In the bend tests attention was focused on the behavior of the weld rather than on that of the entire composite specimen. Subject to these conditions, the principal results and conclusions may be stated as follows:

(*a*) In terms of bend-test performance, the welds susceptible to microcracking were found to be greatly benefited by preheating. The nonsusceptible welds appeared to be affected little if any.

(*b*) In general there was found to be a strong correlation between bend test performance and the occurrence of microcracking. There was, however, little if any correlation with microhardness or with the breadth of the heat-affected zone.

(*c*) A preheating temperature of 130° F was found sufficient to inhibit microcracking in the welds which were susceptible in the absence of preheating. This treatment was found to exert little effect on the rapidity of elevated-temperature cooling but it profoundly influenced the course of cooling at lower temperatures. (The time required for the cooling weld to reach 200° F was increased severalfold by preheating at 130° F.)

(*d*) In the absence of preheating the microcracking of susceptible welds was found to occur at temperatures below 212° F.

(*e*) On the basis of the above indications (and subject to the experimental conditions imposed), it would appear that the benefits of preheating were realized chiefly through the slowing of low-temperature cooling and the consequent inhibition of microcracking.

(*f*) The conditions which were imposed in the investigation are believed to be of interest to users of welding since the cooling rates which were developed are sometimes approximated in practice.

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Temper Brittleness in Low-Alloy Steel Weld Metal

Discussion by W. S. Pellini and P. P. Puzak

The authors have applied the most advanced concepts of ductility and fracture transition of notched specimens to the development of a simple and rapid test procedure for the evaluation of embrittlement in Ni-Mo-V welds. The test method should serve as a practical shop tool for evaluation of the effects of heat treatment of such welds.

A similar investigation by the discussers[1] utilizing Charpy V transition curves resulted in essentially similar conclusions regarding the stress relieving characteristics of Ni-Mo-V (120 T. S. Grade) and Mn-Mo (100 T. S. Grade). There is general agreement, for example, that the Mn-Mo grade is not embrittled by common stress-relieving heat-treatment practices while the Ni-Mo-V type is seriously embrittled. There are, however, certain differences of detail in the results of the two investigations which are of considerable practical significance, particularly with respect to the heat treatment recommendations for Ni-Mo-V (120 T. S.) welds which evolve from the findings. A discussion of these differences should serve to resolve various divergent conclusions.

It appears that the basis for the main points of divergence lie in the different sensitivities of the two test methods to the embrittling and recovery cycles which resulted from the various heat treatments. Thus, for example, the Charpy V test recognizes the following trends of embrittlement at 1050° F in comparison to the notch-bend tests:

	Charpy V, 15 ft, Temp., ° F	*Significance of Charpy V data*	*Wentworth & Campbell notch-bend tests*
As deposited	~ −100	Equal to high quality Q. & T. alloy steel	4% lat. cont.
4 hr at 1050° F	50	Equal to average quality structural mild steel	1% lat. cont.
24 hr at 1050° F	140	Equal to highly embrittled, strain-aged structural mild steel	1% lat. cont.

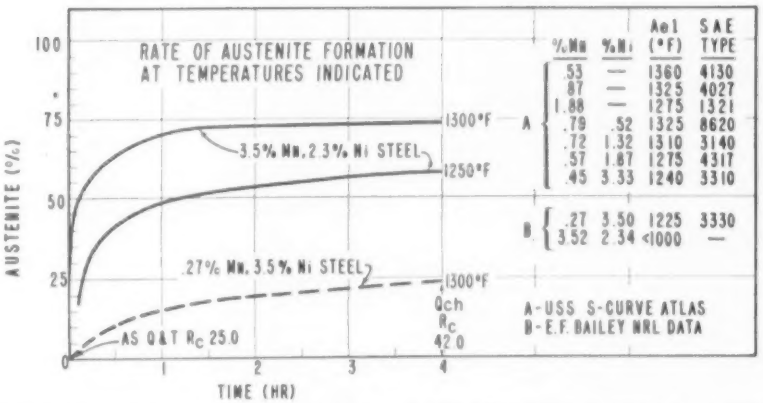

Fig. 1 Rate of austenitization at 1300° F of two alloy steels of varying Mn and Ni contents

Similar comparisons at other temperature ranges indicate that while the two tests generally agree as to gross trends the Charpy test covers a wider range of notch toughness levels and is thus capable of drawing more exact differentiations of heat treatment effects. The limitations of the notch-bend tests are not specific to the test piece utilized by the authors but represent a general limitation inherent to the use of notch-bend specimens at a single temperature, i.e., temperature transition not determined.

The Charpy V specimen indicates that full and complete recovery of the as-deposited notch toughness is obtained only at times of approximately 2 to 4 hr at 1250° F and at times greater than 24 hr at 1200° F. Unfortunately, the notch toughness recovery is not accompanied by a strength recovery and the subject welds accordingly do not meet the minimum tensile specification of the class; both investigations recognize this fact. The notch-bend test indicates apparent full recovery over a broad range of times at 1200 and 1250° F for which the Charpy V test indicates a partial recovery to notch toughness values equal to or less than shown by E6010 deposits. Inasmuch as the notch toughness level of E6010 deposits (or poorer) is inadequate for welds which join Q. & T. steels of high notch toughness (notch toughness match not obtained), it must be concluded that the 1200 to 1250° F "ductile" region (Fig. 3 of Wentworth's and Cambell's paper) shown by the notch-bend test requires cautious interpretation.

The second stage embrittlement shown by holding at 1250° F for times longer than 4 hr was ascribed to austenite formation and the deduction was confirmed by dilatometric tests for austenite formation which indicated 1250° F as the approximate Ae_1 temperature. Accordingly, heat treatments were not conducted at temperatures higher than 1250° F since the rate of austenite formation should be expected to increase markedly. Therefore, there is a major disagreement in the conclusions of the two tests—on the one hand, the Charpy V tests indicate that 1300° F holding should be expected to be detrimental (6% austenite determined dilatometrically to form in 4 hr at 1300° F), while the notch-bend tests suggest a beneficial effect.

The 1300° F hold followed by slow cooling should be considered carefully from the standpoint of the steel which is welded. The 120,000 T. S. grade welds are ordinarily used for the welding of Q. & T. alloy

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Paper by R. P. Wentworth and H. C. Campbell was published in THE WELDING JOURNAL, 31 (11), Research Suppl., 505-s to 514-s (1952).

steels which usually have sufficient Mn and Ni contents to result in austenite formation at this temperature (Mn and Ni have a strong effect in decreasing the lowest temperature level of austenite formation, i.e., the Ae_1 temperature). Figure 1 illustrates the effect of 1300° F hold on the rate of austenitization of two alloy steels of varying Mn and Ni contents. The 0.27% Mn–3.5% Ni steel represents a common type used in heavy sections. The Ae_1 temperatures of other common steels are also indicated from which it may be deduced that steels having contents of Ni and Mn which exceed 1% develop austenite formation at 1300° F. Slow cooling from this temperature should be expected to be deleterious to such steels since poor quality microstructures will be formed at grain boundaries which represent the regions of primary partial austenitization.

Slow cooling from 1300° F should also be expected to effect adversely the notch toughness of many alloy steels by virtue of the development of temper brittleness. In this respect, as well as in the respect of the nature of the embrittlement which is developed in the Ni-Mo-V welds proper, it should be noted that temper embrittlement is a distinctly different type of embrittlement from that which results from age-hardening reactions. Figure 2 presents "C Curve" data[2] indicating the development of temper brittleness in two alloy steels. The maximum rate and extent of temper embrittlement is developed at approximately 950° F; the maximum and minimum temperatures at which embrittlement may be developed depends on the type of steel—1200 and 800° F represent the approximate maximum range. In contrast to age-hardening reactions, overaging (recovery) effects by prolonged holding at embrittlement temperatures are not developed; i.e., recovery is possible only by heating to subcritical temperatures above the highest embrittlement range and cooling rapidly from these temperatures. Temper embrittlement is generally recognized as a grain boundary phenomenon while age-hardening reactions represent general precipitation throughout the matrix. For this reason, strength changes do not accompany the development of temper brittleness—extreme embrittlement indicated by notch-toughness determinations develop no measurable changes whatsoever in tensile strength, hardness or tensile ductility; this is in marked contrast to the strength and hardness changes which were observed to be concomitant with the aging embrittlement of the Ni-Mo-V welds.[1]

The temper embrittlement susceptibility of alloy steels is generally proportional to the hardenability of the steel; molybdenum generally has a restraining effect; however, molybdenum additions alone cannot be considered to be a cure inasmuch as many molybdenum steels are strongly susceptible to temper brittleness (Steel B of Fig. 2 provides an example).

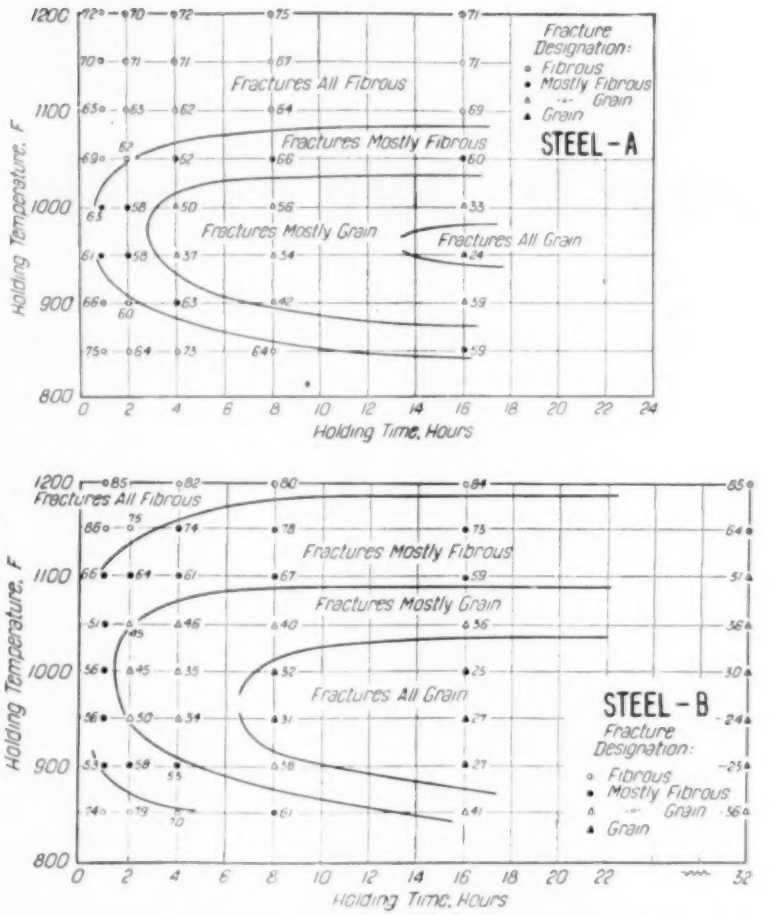

Fig. 2 Effect of temperature on the development of temper brittleness in two alloy steels. The values given are average Charpy V impact energies in ft-lb obtained on duplicate tests made at −60° F

	C, %	Mn, %	Ni, %	Cr, %	Mo, %	V, %
Steel A	0.33	0.23	3.78	1.79	...	...
Steel B	0.44	1.64	1.84	1.64	0.40	0.15

Slow cooling through the temper brittle range results in the development of temper embrittlement roughly equivalent to holding the steel isothermally at the temperature of maximum rate for the equivalent time of cooling from 1200 to the 950° F temperature (max rate temperature). Slow cooling from 1300° F of steels which are susceptible to temper embrittlement should be expected to result in severe embrittlement. For further discussion of this problem the reader is directed to Reference 2.

This analysis, in relation to the steels, also indicates that stress relieving, i.e., holding at 1000–1100° F followed by slow cooling should be highly damaging to many alloy steels. The high notch toughness properties of Navy Special Treatment alloy steel for which the Ni-Mo-V (120 T. S.) weld was originally developed are completely ruined (steel becomes more brittle than mild steel ship plate) by such treatment. Such considerations indicate the need for a careful check as to the temper brittleness characteristics of the alloy steel which is welded, prior to the use of stress relief heat treatment. It should be recognized that the general use of stress relief treatment (subcritical) or of a 1300° F hold (supercritical) and slow cooling variation treatment which is proposed may be highly detrimental for many alloy steels. A check of the molybdenum content provides no general assurance (as is erroneously considered) that temper embrittlement is prevented. As a general guide, steels which contain less than 0.30 % Mn are made safe by moderate additions of Mo; however, steels which approach 1% Mn are difficult to protect completely by Mo additions.[2]

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2. Pellini, W. S., and Queneau, B. R., "Development of Temper Brittleness in Alloy Steels," *Trans. ASM*, 39, 139–161 (1947).

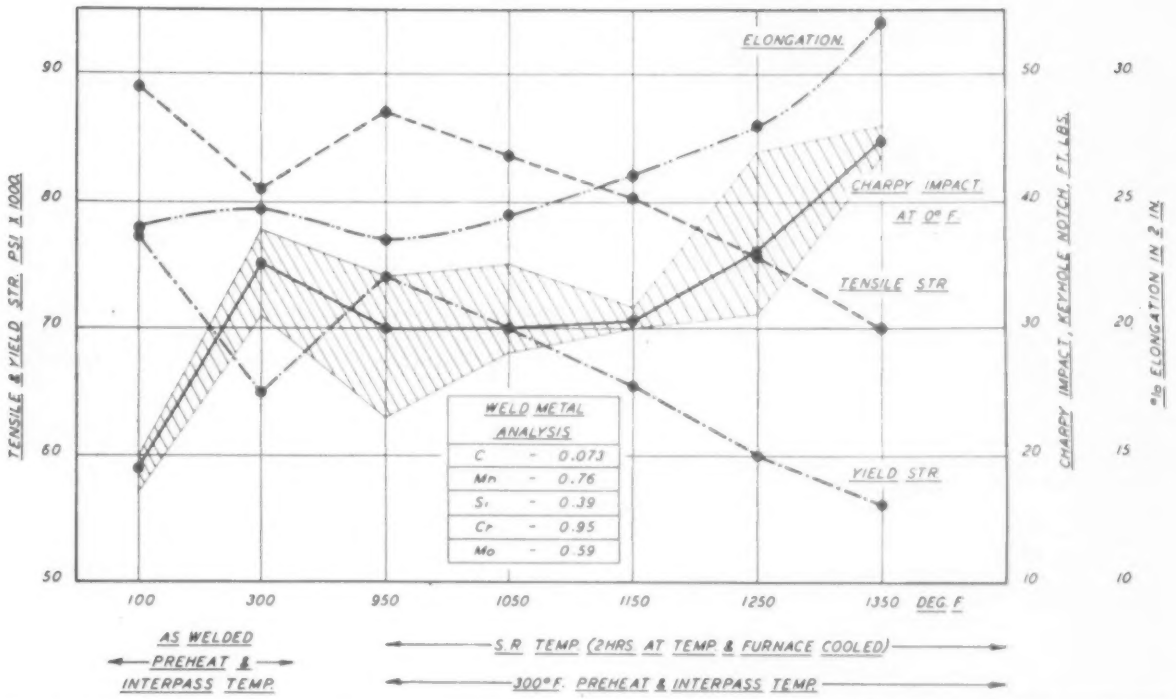
ELONGATION
CHARPY IMPACT AT 0° F.
TENSILE STR
YIELD STR
WELD METAL ANALYSIS
C - 0.073
Mn - 0.76
Si - 0.39
Cr - 0.95
Mo - 0.59
TENSILE & YIELD STR PSI X 1000
CHARPY IMPACT, KEYHOLE NOTCH, FT. LBS.
% ELONGATION IN 2 IN.
100 300 950 1050 1150 1250 1350 DEG. F
AS WELDED
PREHEAT & INTERPASS TEMP.
S.R. TEMP. (2HRS. AT TEMP. & FURNACE COOLED)
300°F. PREHEAT & INTERPASS TEMP.

Fig. 3 Effect of stress-relieving temperatures on the mechanical properties of an AWS E 8016 (1Cr – ½Mo) electrode weld metal

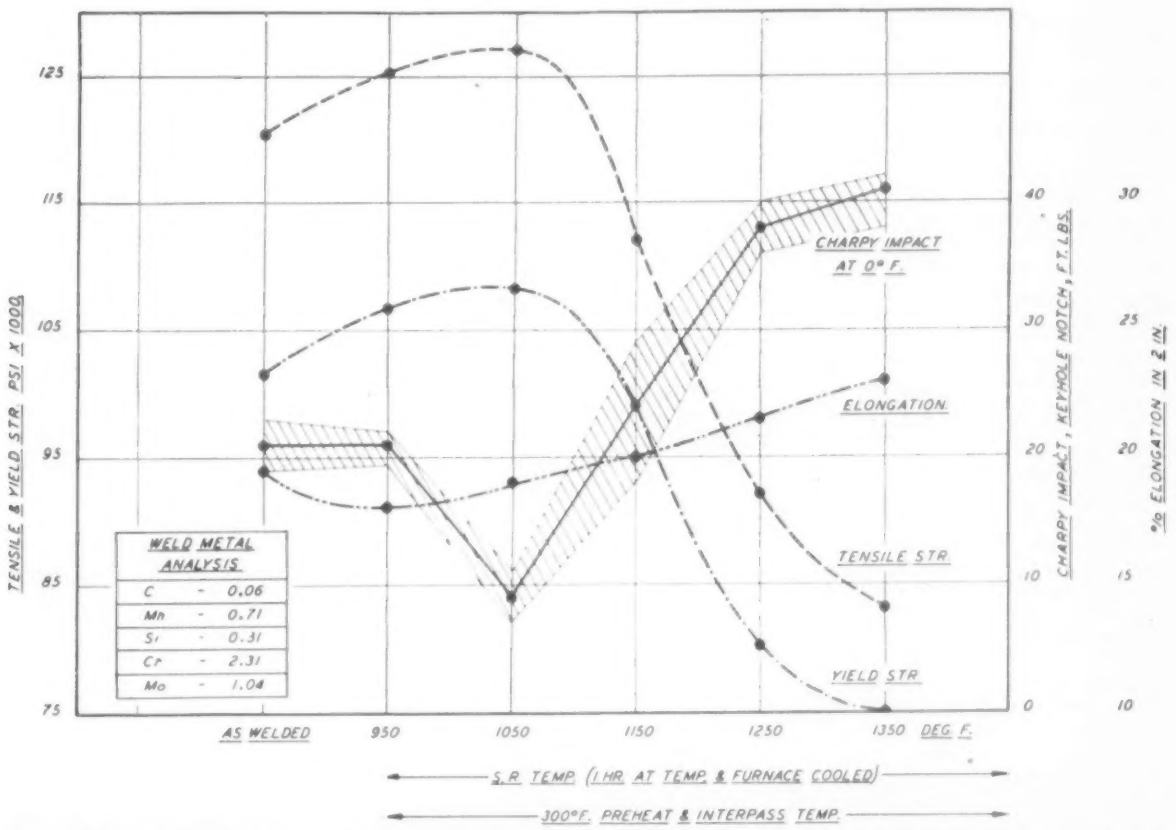
CHARPY IMPACT AT 0° F.
ELONGATION
TENSILE STR
YIELD STR
WELD METAL ANALYSIS
C - 0.06
Mn - 0.71
Si - 0.31
Cr - 2.31
Mo - 1.04
TENSILE & YIELD STR PSI X 1000
CHARPY IMPACT, KEYHOLE NOTCH, FT. LBS.
% ELONGATION IN 2 IN.
AS WELDED 950 1050 1150 1250 1350 DEG. F.
S.R. TEMP. (1 HR. AT TEMP. & FURNACE COOLED)
300°F. PREHEAT & INTERPASS TEMP.

Fig. 4 Effect of stress-relieving temperatures on the mechanical properties of an AWS E 9016 (2Cr – 1Mo) electrode weld metal

Discussion by D. C. Smith and W. G. Rinehart

It is gratifying to see papers such as this one on "Temper Brittleness in Low-Alloy Steel Weld Metal" published, and the authors are to be congratulated for their systematic investigation of these five different compositions. It is hoped that more work of this type will be published on electrode weld metal in order to give the consumer a better background on which to make an intelligent electrode selection for a particular job. Too often this type of information is readily available on the steel being welded but not on the electrode used in making the weldment. We are also pleased to see from their results the good correlation between the simplified notched-bend method for checking notch toughness and the Charpy keyhole or V-notch method as a means of investigating brittleness in metals.

Since publishing our paper[1] on the "Heat Treating Properties of Low-Hydrogen Electrode Weld Metals" we have investigated the impact properties of several other weld metal compositions and we feel that the results on two, herein given in Figs. 3 and 4, (page 109-s) will be of general interest and support the findings of the authors of this paper.

While it has been quite well established that some elements are more prone to cause temper brittleness than others, their effect in combination with other alloying elements is not too well understood, particularly in weld metal of low-carbon content (less than 0.12%). Archer, *et al.*,[2] state that molybdenum is used to decrease temper brittleness in silicon-chromium and intermediate chromium steels. However, in these steels the molybdenum content was less than one-half per cent.

Weld metal compositions reported in our paper and several others which we have investigated have shown that when the molybdenum content is over one-half per cent there is a definite tendency for temper embrittlement. The data in this paper also confirms this.

With the 1% Cr -1/2% Mo composition (Fig. 3) there is little if any temper brittleness as shown by the Charpy impact determination at 0° F, but the 2% Cr - 1 % Mo type (Fig. 4) shows a definite embrittlement in the temperature range between 950-1150° F. The 1% Cr -1/2% Mo test specimens were held at the stress relieving temperature for 2 hr and furnace cooled at the rate of approximately 60° F per hour, and the 2% Cr - 1% Mo specimens were held at temperature for 1 hr only and furnace cooled. While it is realized that these determinations were not systematically carried out to show the effect of both time and temperature, it is felt that this data plus the other work we have done indicates that high molybdenum and low carbon tend to produce temper embrittlement.

In conclusion, we believe that the data presented in this paper and that of ours indicate the importance to the consumer of knowing the effect of thermal treatment on the mechanical properties of the electrode weld metal he intends to use for a given job. Furthermore, this work points out the need for a more thorough study of this kind on all types of alloy composition, particularly where high-tensile strengths are desired in the weld metal of low-carbon electrodes designed to be used with little or no preheat followed by a stress-relieving treatment.

References

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Authors' Reply

This additional contribution from the Harnischfeger Laboratory is a welcome extension of the Smith and Rinehart paper on low-hydrogen electrodes. Their observations on the adverse effect of molybdenum in these low-alloy grades has prompted us to test a 2% Cr - 1% Mo electrode with the notched-bend specimen.

In order to explore the time-temperature effect, we tested specimens heat treated for four different times at four different temperatures. Figure 5 shows our results. The welding procedure duplicated our previous practice, except for the use of 300° F preheat and interpass temperature to match the Smith and Rinehart study.

The high Brinell values for the as-welded specimen and those specimens tempered at 950 and 1050° F indicate that this grade is subject to some as-welded brittleness; however, the results also indicate that there is a secondary embrittlement effect. It will be observed that, even though there is a decrease in hardness with time at 950° F, there is an apparent increase in brittleness as evidenced by the percent contraction values.

Again, the importance of time of holding at temperature is observed. If only the 1- and 4-hr results at 950 and 1050° F are considered, the smaller percent contraction values at the higher temperature indicate that some secondary embrittlement has occurred. However, as mentioned above, a longer time at 950° F has further embrittled the weld metal. Possibly some embrittlement would be present at lower temperatures, if sufficient times were employed.

Thus, our results check the Smith and Rinehart data, indicating that some temper brittleness is present in this grade, but, since we have employed longer times, the brittleness was also revealed at 950° F.

Further investigations of this grade appear desirable, including a study of the effect of prior heat treatment. In a written discussion of our paper, W. S. Pellini and P. P. Puzak[1] have presented a very clear and authoritative interpretation of the ASM paper by Pellini and Queneau,[2] a paper which is referred to in our paper and theirs. The distinction Pellini and Puzak make between temper brittleness and age hardening was not made clear in the ASM paper. Both Smith and Rinehart and Wentworth and Campbell have used the term "Temper Brittleness" in describing the behavior of certain of these low-alloy weld metals. The term has a popular and descriptive connotation which seemed to fit the embrittlement as it was first observed and reported. However, Mr. Pellini has made a convincing plea for a distinction between non-recoverable

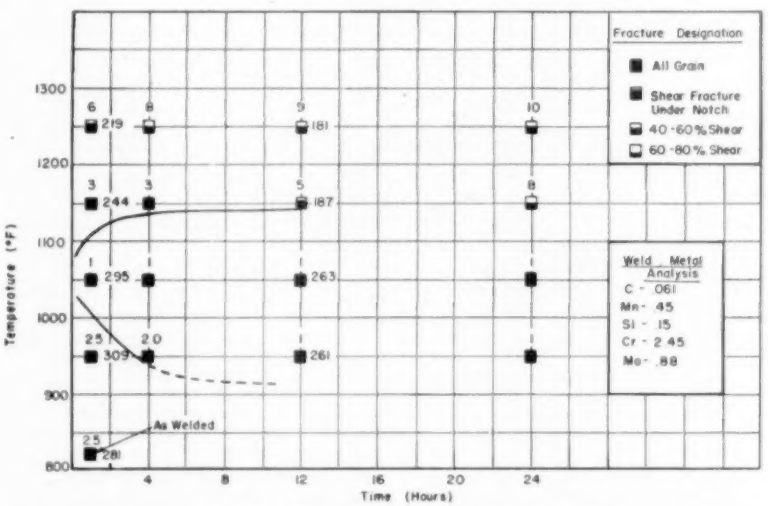

Fig. 5 Brittle range in 2Cr-1Mo weld metal. Numerals above fracture indications are percent contraction values beneath the notch. Brinell hardness readings are indicated beside the 1-hr, 12-hr and as-welded specimens

D. C. Smith is Chief Metallurgist and W. G. Rinehart, Research Metallurgist, Harnischfeger Corp., Milwaukee, Wis.

temper brittleness and the recoverable age-hardening embrittlement which seems to be involved in some of the present studies. For that reason further studies should be made of 2 Cr – 1 Mo specimens which a previous treatment has placed in a notch-tough condition. If brittleness is developed in these specimens on tempering, then temper-brittleness would seem to be involved. However, if the brittleness can be cured by overaging, the type of brittleness present in the Ni–Mo–V grades is involved.

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2. Pellini, W. S., and Queneau, B. R., *Trans. ASM* **39,** 139–161 (1947).

Chromium Recovery During Submerged Arc Welding

Discussion by Frank G. Harkins

Messrs. Kerr and Elmer have performed a notable service through their study of chromium loss in the submerged-arc welding process. Each fabricator who has attempted to weld the many grades of stainless steel by means of this high production process has experienced considerable difficulty due to incipient and underbead weld metal cracking. Chemical analysis of the deposited weld metal by numerous investigators has shown that chromium losses up to 30%, presumably due to oxidation, have occurred.[1] A specific instance which occurred within this company was a problem involving the welding by the submerged-arc process of a 1/8-in. thick plate of AISI Type 347 Stainless to a 3/4- by 1/2-in. thick bar of the same material.[2] The weld metal, as called out on the engineering drawing, was required to conform to the AISI Type 347 specifications. Severe cracking, extending from the center of the weld bead to the root of the weld, occurred whenever a normal submerged-arc machine adjustment was employed. This cracking was subsequently demonstrated to be caused by a combination of the mechanical arrangement of the weld joint, the shape of the weld bead and a relatively high nickel content in the weld metal. It has been shown in all of the data which has been published by the International Nickel Co. that all high-nickel alloys exhibit hot short tendencies in the 1000 to 1400° range. It has been suggested by numerous investigators that the hot short range in the nickel alloys is due primarily to some sort of intergranular precipitation. It has been shown by means of several papers by R. D. Thomas, Jr., and Alton L. Schaeffler that the cracking tendencies in all austenitic weld metal can be controlled by the introduction of several ferrite formers into the weld metal. Loss of chromium (which is relatively strong ferrite former) upsets the balance of the alloy causing the weld metal to become completely austenitic. According to Henry and Claussen,[3] the relative ability of chromium to form ferrite may be shown by the factor 1. Molybdenum and columbium have a factor of 2. Silicon, as a ferrite former, has a factor of 1, while titanium has a factor of 5.

If we assume a chromium loss of 30% in submerged arc welding with an 18–8 type filler wire, the deposited weld metal would be of the nature of a 12 chrome–12 nickel steel. No investigator has shown nickel losses in welding operations. Schaeffler shows in his chromium equivalent—nickel equivalent charts (*Welding Metallurgy*, by Henry and Claussen, page 446)—that the weld deposit of a 12 chrome–12 nickel alloy must be fully austenitic and, therefore, susceptible to hot short cracking. The suggestion by the authors to compensate the chromium loss by the introduction of chromium-rich ores into the welding flux is sound. This practice has been employed in our plant with considerable success. It has also been demonstrated as shown in Fig. 4 in the Kerr-Elmer paper that percent of chromium recovery is inversely related to the arc voltage. It is unfortunate indeed that Fig. 4 has not been projected downward to voltage lower then 22, because it has been observed over a period of 3 1/2 yr of operation using an 18–8 filler wire that chromium loss in passing across the arc could be held to 1–2% through the utilization of arc voltages in range of 16 to 18.

It may be of interest to note that our experience parallels that of the authors in the selection of fluxes containing relatively low percentages of manganese and silicon. However, it has been shown by Page in a paper, "Chemical Factors Affecting the Weldability of 18–8 Steels," THE WELDING JOURNAL, October 1945, that the presence of silicon in controlled quantities is essential to stainless steel of good weldability. Page demonstrated that the optimum range of silicon was in the range of 0.5 to 1.0%.

It is our standard practice to specify 18–8 steels from the mills which contain silicon in this range. However, according to Thomas and Schaeffler, in AISI Type 310 (25–20), silicon above 0.6% is detrimental to the welding operation. This has been confirmed by several investigators. The presence of substantial quantities of silicon contributes to incipient and underbead weld

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Paper by James G. Kerr and David A. Elmer was published in THE WELDING JOURNAL, **31** (9), Research Suppl., 431-s to 438-s (1952).

metal cracking. Similarly, the International Nickel Co. goes to considerable effort to maintain the silicon content of their alloys at relatively low levels. Solar Welding Fluxes for stainless steels containing up to 20% nickel are composed of 52% silicon compounds. These are not recommended for any materials in which the nickel content exceeds 20%, since it is highly probable that high-temperature embrittlement or cracking will occur.

In welding such alloys as 25–20, Inconel, N-155 and the Stellites, a special low-silicon, low-boron flux has been developed, which is known as Type I Solar Flux. This is a fluorine compound base flux.

From the preceding discussion, the impression might be given that silicon as such, is an undesirable element in stainless steels. This is certainly not the case, as is exemplified by the fact that a typical coating for Type 347 stainless steel metallic arc electrodes contains over 20% silicon compounds. The binder for the various ingredients is sodium silicate.

It has been observed in our shops that if the silicon content of stainless steels of the so-called 18–8 type falls to 0.3% or lower, the steel may be welded without difficulty by the metallic-arc process only.

It has been observed in the large-scale welding of relatively thin sections of the various stainless steels that the amount of a specific element which a steel contains is not so important as the relationship of the various elements. If the chromium-nickel ratio can be held in the ratio of 1.9/1, and the manganese-silicon ratio of 2/1 with silicon in the range of 0.5 to 1.0%, weld metal cracking is extremely rare.

It is recognized that this statement is an oversimplification since the effects of aluminum, calcium, fluorine, magnesium, etc., have not been evaluated and from the practical standpoint need not be evaluated since the aim of most welding operations is simply to produce a sound weld of the required properties.

The above discussion is not intended to imply that the welding of stainless steels by means of the submerged-arc process using an 18–8 type filler wire is recommended unless it is essential, as regards the end use of the product, that the deposited weld metal meet the requirements of the AISI specifications for Type 347 material.[3] The application of 347 filler wire will require: (*a*) perfect fit-up of the parts; (*b*) jigging or fixturing in such a manner that the weld, when cooling, is in compression rather than tension or shear and (*c*) that arc voltage be maintained at not over 18 v. If these fundamental requirements are met, 18–8 type wire may be employed for submerged arc welding. It is much simpler, however, to anticipate chromium loss in the section of the filler wire. A filler wire which has consistently good results is wire of the 29 chromium–9 nickel type. This is AISI Type 312. It is practically impossible, regardless of arc voltage, current input or speed of welding, to cause cracking of whatever nature in deposited weld metal on Type 347 stainless steel base metal when using Type 312 wire. The chemical analyses of the deposited weld metal will be of the nature of a 21 chrome–10 nickel alloy. This alloy contains sufficient chromium and has picked up sufficient columbium from the base metal to insure the presence of substantial quantities of ferrite in the deposited weld metal. In welding the austenitic stainless steels the importance of ferrite as a means of preventing weld cracking cannot be overemphasized. This must be obvious when one considers that welding rod specifications require a chrome-nickel ratio of not less than 1.9 to 1. This is further exemplified by the fact that castings steels of the 18–8 type must have the same chrome-nickel ratio if excessive cooling cracks are to be avoided. It is further demonstrated by the observation of users of 18–8 type materials in the stabilized grades that Type 321 steel is much less susceptible to weld cracking than Type 347 steel. Study of the chemical analysis of these steels show typically 18 chrome–8 nickel for Type 321 steel and 18 chrome–12 nickel for Type 347 steel. Type 321 steel[4] has superior mechanical properties as regards formability, weldability, high-temperature strength and scaling resistance. It is felt that the authors, Messrs. Kerr and Elmer, are deserving of the highest commendations from the AMERICAN WELDING SOCIETY for this worthwhile contribution to the science.

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Welding 2½ in. x 2½ in. x ¼ in. galvanized angle iron frame with $^{3}/_{16}$ in. Everdur-1010 Welding Rod.

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These galvanized angle iron frames are used to support air conditioning coils in the new Prudential Insurance building in Houston, Texas. Welding on the frames was done from both sides of the 2½ in. x 2½ in. x ¼ in. angles, laying a comparatively small bead. Leaving a $^{1}/_{16}$ in. gap between the legs allowed the Everdur-1010 Welding Rod to "tin" more than halfway through the thickness of the angle. The arc cone was directed as much as possible on the Everdur weld deposit resulting in a minimum disturbance of the galvanized plating. Straus-Frank Company, welders in Houston, Texas, tested the efficiency of the joint by attempting to shear an angle clip (as shown in the lower right hand photograph) from the frame with a four-pound hammer. The legs of the angle were pounded flat—but no failure in the weld area occurred. ANACONDA Rods for every type of welding are available from distributors throughout the United States and Canada. For complete information on ANACONDA Welding Rods *plus* tips on practical welding techniques, send for Publication B-13. Address The American Brass Company, Waterbury 20, Connecticut. In Canada: Anaconda American Brass Limited, New Toronto, Ontario.

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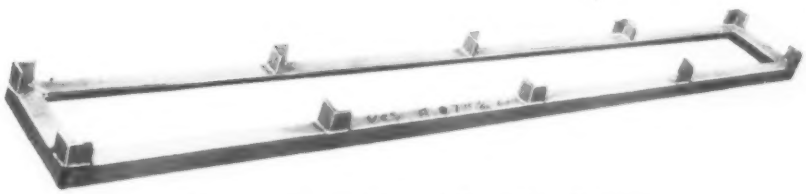
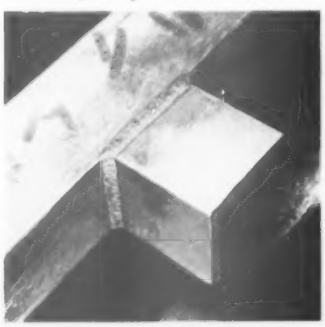


Here is the finished frame used to support cooling coils in the New Prudential Insurance building, Houston, Texas.

Close-up of Everdur weld joining an angle clip to the frame.



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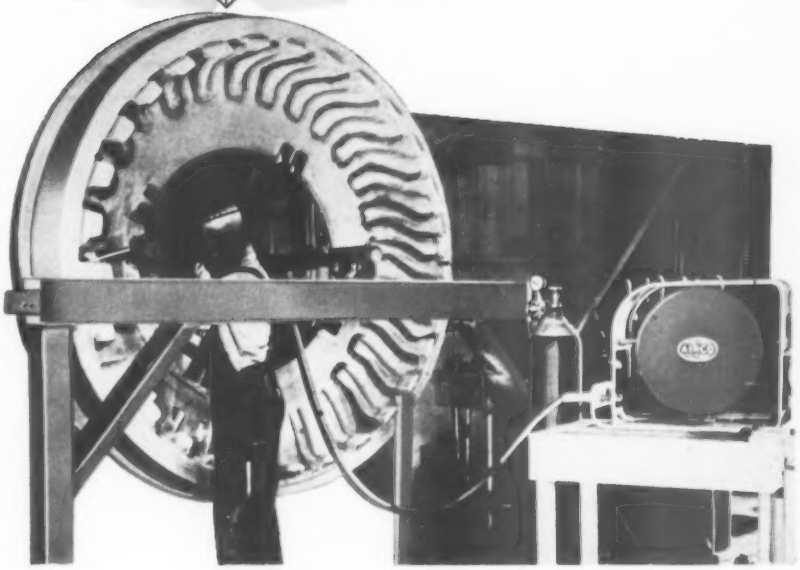

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